(12)

AD

ADA115292

AMMRC TR 82-11

THE EFFECT OF ENVIRONMENT ON THE MECHANICAL BEHAVIOR OF KEVLAR/EPOXY MATERIALS

March 1982

T. HO
Vought Corporation
Advanced Technology Center
P.O. Box 226144
Dallas, Texas 75266

FINAL REPORT

Contract Number DAAG46-80-C-0037

Approved for public release; distribution unlimited.

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AMMRC TR 82-11
2. GOVT ACCESSION NO.: AD-A115892
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): The Effect of Environment on the Mechanical Behavior of Kevlar/Epoxy Material
5. TYPE OF REPORT & PERIOD COVERED: Final Report May 1980 - September 1981
6. PERFORMING ORG. REPORT NUMBER: R-92000/1CR-60
7. AUTHOR(s): T. Ho
8. CONTRACT OR GRANT NUMBER(s): DAAG46-80-C-0037
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Vought Corporation Advanced Technology Center, P. O. Box 226144, Dallas, Texas 75266
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: Army Materials and Mechanics Research Center, Attn: DRXMR-K, Watertown, Massachusetts 02172
12. REPORT DATE: March 1982
13. NUMBER OF PAGES: 121
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Deterioration, Viscoelasticity, Mechanical Properties, Kevlar Epoxy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Applicability of a viscoelastic characterization to Kevlar 49/5208 material under severe environment was investigated. Specific studies include development of properties reflecting material dependence on time, temperature and humidity and resolution of the question as to whether a specific thermal conditioning environment can be directly substituted for a specific moisture conditioning environment over a prescribed temperature vs. humidity range. Specimens with 0°, 90° and $\pm 45^{\circ}$ layup were used for creep-recovery tests in various environments. Test data were analyzed by using a viscoelasticity theory (next page)

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block No. 20

and power law representation of the creep compliance. Stress dependence of the material is emphasized to account for non-linearity.

FOREWORD

This final report is for the research program entitled "The Effect of Environment on Mechanical (Viscoelastic) Behavior of Kevlar/Epoxy Material," and the work has been conducted by Vought Corporation Advanced Technology Center. This final report covers the activities from the period 5 May 1980 to 5 September 1981 and is sponsored by the Army Materials and Mechanics Research Center under Contract Number DAAG46-80-C-0037.

Dr. M. E. Roylance is the Army Project Manager and Dr. W. J. Renton is the Vought Program Manager. Other key personnel are Dr. T. Ho, Principal Investigator; Mr. C. L. Cooper, Associate Investigator; and Dr. R. A. Schapery, Texas A&M University, Technical Consultant.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The wide usage of advanced composite materials in future aerospace systems is projected to become a reality in the next few years. Army helicopters, such as the ACAP, are candidate weapon systems dependent on composite materials for primary and secondary structural components.

Presently, the response of advanced composite materials to arbitrary load and environments is known to have a significant adverse effect on the materials performance. Kevlar/epoxy material response in severe environments is unique in that with both its fiber and resin being organic, both are susceptible to temperature and/or moisture degradation. Thus a potentially significant viscoelastic dependence of the fiber and the fiber dominated properties of the composite is anticipated. This may result in the observance of both elastic (spring) and viscous (dashpot) degradation of the material system. This in turn could have a most significant effect on the materials response in stress rupture and fatigue design applications for Army weapon systems, such as the components under development on the current All Composite Airframe Program.

The objective of this research program was to ascertain if the mechanical response of Kevlar/epoxy composite material, subjected to various time, temperature and moisture effects, could be characterized using traditional viscoelastic shift factors, and to formulate the compliance of material property dependence on time, temperature and humidity.

This was an exploratory study with the mechanical response of the Kevlar/epoxy being simplified so that the effect of crack growth is minimized. This was accomplished experimentally by mechanically stabilizing the specimen response prior to the characterization tests.

Conventional viscoelasticity theory was used as the theoretical base in conducting the creep and recovery tests. Data generated in this report was from tests of $(\pm 45)_{2S}$ specimen at sixteen temperature and humidity environments and from tests of $(0)_8$ and $(90)_{20}$ at four temperature environments. Three stress levels were used for each environment. Preliminary analysis indicates that power law representation for the Kevlar 49/5208 is an adequate approach in quantifying the viscoelastic response.

2.0 SPECIMEN FABRICATION AND ENVIRONMENTAL CONDITIONING

2.1 SPECIMEN FABRICATION

Kevlar 49/Narmco 5208 material (12-inch prepreg, Batch #1571) was used for specimen fabrication. The resin content from the Narmco data sheet was listed as 44% by weight and the prepreg density as 125 gm/m^2.

Initially, four panels with dimensions 28" x 18" x 20 ply and two panels with dimensions 28" x 18" x 8 ply were fabricated immediately following receipt of material. Quality analysis by ultrasonic C-scan indicated that the 20-ply panels showed large areas of discoloration from a large population of air bubbles trapped in the laminate. Subsequently, volatile content tests were conducted on the prepreg. Vought observed a 2.6% volatile content and Narmco found a ?.5% volatile content. These volatiles are the primary contributor to panel porosity. A series of panel fabrication procedures (Table 1) were experimented with to eliminate the porosity in the cured panels. Based on the results for acceptable panels (O, J-1 and p in Table 1), two additional requirements were added to the normal process procedure:

a. Plies need to be dessicated for at least six days before laying up.

b. No bleed layup for either the Vought or Narmco process procedure is necessary.

The representative process procedures for Narmco and Vought are shown in Appendices A and B, respectively.

Following the normal cure cyle (350^{o}F cure) and the two additional requirements, five composite panels as shown in Table 2 were fabricated. The prepreg plies were dessicated for six days (144 hours) before they were layed up and bagged for curing.

The fabrication procedure from which the specimen is made is illustrated in Figure 1. A wafering diamond cutter was used to cut the panels into the individual specimen coupons. The typical finished surfaces of the specimens are shown in Figure 2. No obvious delaminations or cracks were induced in the cutting. No obvious porosities were found in the specimens. The bonding of the E-Glass tab using AF126 adhesive to the Kevlar/5208 panels was performed at 250^{o}F instead of 350^{o}F in order to avoid the laminate cracking in the unidirectional laminate. The thermal expansion coefficient difference between the glass tab and the Kevlar panel will cause the cracking. Each specimen has the dimensions of 7" long by 0.75" wide with a tab length of 1.5".

2.2 ENVIRONMENTAL CONDITIONING

As summarized in Table 3, there are sixteen different combinations of temperature and humidity levels for the program. They represent an even distribution of temperature and humidity that covers the characteristics of the material properties. Originally, one stress level for testing was planned in each environment. Due to the increasing importance of non-linearity in the fatigue characterization, three stress levels were selected for testing in most environments in order to account for the possible non-linear nature of Kevlar/epoxy.[2] Before testing, each specimen was conditioned to the desired moisture level (close to 95% saturation of the epoxy) in the conditioning chamber. For specimen conditioning, three of the four humidity environments use salt solutions as indicated in Table 4. The room temperature humidity (RTH) environment in Table 4 is the daily laboratory temperature and humidity atmosphere. Its yearly moisture variation is between 30% and 70% R.H. and that of temperature is between 55°F to 95°F. The moisture absorption rate in the conditioning chamber at 170°F temperature is shown in Figure 3. The samples used for the moisture absorption rate study were 1" by 1" square size with an average thickness of .116" and were an $(0^{\circ})_{20}$ layup. The weight gain percentage shown in Figure 3 uses the base weight after fabrication. Based on the data, the time required to condition a 20 ply layup to 95% saturation of the epoxy constituent at 170°F needs approximately 4.5 months. Thus, thirty days conditioning is required for specimens 0.045" thick for eight-ply laminates. The 170°F temperature (instead of higher temperature) for the moisture conditioning environment was chosen so that the induced microcracks from the hygro-thermal effect can be minimized.

3.0 MECHANICAL CHARACTERIZATION

It has been shown by Allred[3] and Smith[4] that characteristics for both Kevlar 49 fiber and Narmco 5208 resin are influenced by temperature and humidity. This will create compound viscoelastic effects and presents a more involved effort in the characterization.

3.1 VISCOELASTIC CHARACTERIZATION OF KEVLAR/EPOXY COMPOSITE

Let $_{ij}$ and ε_{ij} $(i,j = 1,2,3)$ denote the stress components and strain components, respectively, in the Cartesian axes x_i $(i = 1,2,3)$. The constitutive equations for the viscoelastic material that has an anisotropic thermorheologically simple material are given by

$$\sigma_{ij} = \int_0^t C_{ijkl} (\zeta - \zeta') \frac{\partial \varepsilon_{kl}}{\partial t'} \, dt' \qquad (1)$$

with $C_{ijkl}(t)$ $(i,j,k,l = 1,2,3)$ as the relaxation moduli and

$$\zeta = \zeta(t) \equiv \int_0^t d\tau / a_T \, , \quad \zeta' = \zeta(t') = \int_0^{t'} d\tau / a_T \qquad (2)$$

ζ is called reduced time and a_T is called the temperature shift factor. The inverse relation, in terms of creep compliances S_{ijkl} are

$$\varepsilon_{ij} = \int_0^t S_{ijkl} (\zeta - \zeta') \frac{\partial \sigma_{ij}}{\partial t'} \, dt' \qquad (3)$$

A quasi-elastic representation can be employed to relate the above viscoelastic constitutive equations in elastic format:

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{12} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} \qquad (4)$$

for unidirectional lamina. Compliances, S_{ij}, will vary with time, temperature and humidity. The purpose of the mechanical characterization of the Kevlar/epoxy composite is to characterize these compliances.

The general form of S_{ij} can be represented in a power law form[7]

$$D(t, T, R.H.) = D_0 + D_1 t^n \qquad (5)$$

where t, T, and R.H. stand for time, temperature and relative humidity respectively. The time independent constants D_0, D_1, and n were evaluted based on experimental results. This power law representation has proven to be satisfactory in characterizing Glass/epoxy[5] and Graphite/epoxy.[6] The experience with power law type characterization suggest that data generated by creep-recovery tests, such as Figure 4, can best be used to evaluate the power law constants, D_0, D_1, and n. This is due to the fact that the net creep compliance $D - D_0$ is usually much smaller (order of magnitude) than the initial compliance, D_0, values. D_0, D_1, and n of equation (5) can not be accurately found from short term creep test data only, where short term means creep test less than an hour. The merit of this creep-recovery data in evaluating power law constants is demonstrated in Figure 4 and as follows.
If σ_0 is the uniaxial creep stress applied to the specimen, $\varepsilon_r(t)$ is the recovery strain, and t_c is the time at which recovery begins, then for $t > t_c$, we have

$$\frac{\varepsilon_r(t)}{\sigma_0} = (D_0 + D_1 t^n) - D_0 + D_1(t - t_c)^n$$

$$= D_1 t^n - D_1 (t-t_c)^n$$

$$= \Delta D(t_c) \left[(1 + \lambda)^n - \lambda^n\right] \qquad (6)$$

where $\Delta D(t_c) = D_1 t^n$ and $\lambda = (t - t_c)/t_c$ for $t > t_c$

Equation (6) may be written in logarithmic form:

$$\log \varepsilon_r = \log \Delta D(t_c) + \log \left[(1 + \lambda)^n - \lambda^n\right] + \log \sigma_0 \qquad (7)$$

The difference between log ϵ_r and Log $[(1 + \lambda)^n - \lambda^n]$ is the constant $[\text{Log}\ \Delta D(t_c) + \text{Log}\ \sigma_0]$. By plotting Log ϵ_r versus Log λ from recovery test data and shifting it vertically to compare with the Log $[(1+\lambda)^n - \lambda^n]$ versus Log λ curves for different n values, the appropriate exponent n can be defined as the one which provides the best match between the curves. Linear regression techniques can then be used to evaluate D_0 and D_1 from the creep test data. Usually, n is a constant and D_0 and D_1 are a function of temperature and humidity. In Section 3.5 this method of obtaining values of n, D_0, and D is used to evaluate the creep-recovery test data. There are sixteen temperature and humidity combinations used to characterize the functional dependence of D_0 and D_1 on temperature and humidity. With the large number of creep-recovery tests involved, the one hour test is preferable to the conventional creep test which characteristically lasts several days.

3.2 SENSITIVITY STUDY

A study was conducted to determine the sensitivity of material compliance to laminate ply orientations and environments. The sensitivity study was conducted on both angle-ply layup and off-angle unidirectional layups, by using DuPont's data for unidirectional tape and the Halpin-Tsai relationships

$$E_{11} = E_f V_f + E_M V_M \qquad \nu_{12} = \nu_f V_f + \nu_M V_M \tag{8}$$

$$E_{22} = E_M \frac{[E_f(1 + \zeta_e V_f) + \zeta_e E_M (1 - V_f)]}{E_f(1 - V_f) + \zeta_e E_M \left(1 + \frac{V_f}{\zeta_e}\right)} \tag{9}$$

$$E_M(t, T, R.H.) = 2(1 + \nu_M)\, G_M(t, T, R.H.) \tag{10}$$

$$G_{12} = G_M \frac{[G_f(1 + \zeta_g V_f) + \zeta_g G_M (1 - V_f)]}{G_f(1 - V_f) + \zeta_g G_M \left(1 + \frac{V_f}{\zeta_g}\right)} \tag{11}$$

Results are shown in Figures 6 and 7. Both Young's Modulus and the shear modulus are sensitive to property degradation in both the fiber constituent and the matrix constituent. Poisson's ratio was less effected.

3.3 GLASS TRANSITION MEASUREMENTS

The effect of conditioning on the thermomechanical behavior of the Kevlar/5208 materials was studied using the Perkin-Elmer model TMS-2 Thermomechanical Analyzer in the expansion mode. The measurements were performed at 20^{o}C/minute on specimens preconditioned for five months at 52% and 95% RH (using saturated solutions of NaBr and NaF respectively), and on specimens which were treated as fabricated. These as-fabricated materials are referred to as dry.

As measured by the TMS-2, the glass transition range in these materials is significantly broadened by moisture absorption, making the characterization of the glass transition temperature increasingly difficult. Included in the data shown in Table 5 are both the range of the glass transition and the temperature at the inflection point in the expansion vs. temperature curve. This inflection point occurs at the approximate midpoint of the temperature range.

It can be seen that in addition to broadening the glass transition the absorption of moisture depresses the transition by as much as 60-70^{o}C. This is in agreement with other work (Roylance and Roylance)[8] which has shown similar depression and broadening of the glass transition in a similar epoxy.

These measured transitions reflect the behavior of the epoxy matrix only, since the dynamic mechanical properties of wet and dry Kevlar fibers have been measured throughout this temperature range and no transition has been observed.[9]

3.4 STATIC TESTS AND DISCUSSIONS

Static tensile strength tests in typical environments for 0^{o}, $\pm$45^{o}, and 90^{o} specimens have been conducted. These test results were used as baseline data for creep-recovery tests, and to evaluate the quality of the material. Test results and related environments are shown in Table 6. A typical test set-up for either the static test or creep recovery test in the Shore Western environmental test machine is shown in Figure 8. Some specimens that were tested at dry environment were strain gaged in order to verify the extensometer recording and to obtain biaxial readings. Strength of the 0^{o}

specimen is beyond the capability, (5000 lbs.), of the Shore Western environmental test machine. An MTS machine was used for these tests instead. Typical stress-strain curves for the composite are shown in Figure 9. Both 0^0 and 90^0 specimens have material linearity up to the failure point. The failure of 0^0 specimens is induced from longitudinal shear splitting between parallel fibers. The 90^0 specimen always fails, in a clean cut fashion, along a cross section parallel to the fiber. The ± 45 specimen is highly non-linear with an axial failure strain exceeding 30,000 μ in/in. The $\pm 45^0$ specimen failed consistently at the gage section of the specimen along either the +45 or -45 direction. This failure mode is similar to that of a $\pm 45^0$ graphite/epoxy specimen or glass/epoxy specimen.

The effect of temperature and moisture on Kevlar 49/5208 can be first gleaned through the data in Table 6. The deterioration of properties for 0^0 and ± 45 specimens are not as dramatic as that of 90^0 specimens. Both strength and modulus of 90^0 specimens are reduced by more than 50% from its room temperature dry condition to 170^0F/95% R.H. environment. Thus, the environmental effect on Kevlar/epoxy composite can not be ignored.

3.5 CREEP-RECOVERY TESTS AND DISCUSSIONS

Creep-recovery tests were conducted on 0^0, $\pm$ 45^0 and 90^0 specimens by using the Shore Western environmental test machine described in Figure 8. An extensometer was attached to the center two inches of the gage section to monitor the creep and recovery deformation. A temperature gage was also used in the gage area to monitor the temperature history on the surface of the specimen and to validate the temperature condition of the Shore Western machine. This is important in that the test assembly, including specimen extensometer and fixture linkages, are all sensitive to temperature variation during the testing. Any thermal contraction or expansion in the test assembly will distort the creep or recovery reading. Past experience with graphite/epoxy composites[6] indicates that a thirty minute period is required to stabilize the environment and test assembly in the closed chamber. After the test assembly was thermally stabilized, the specimen was loaded and unloaded roughly four times at the rate of 3 cycles per minute in order to mechanically stabilize test assembly linkage so that it will yield respectable test cycles and reproducible test results. Figure 10 shows the typical strip chart output concerning thermal and mechanical conditioning in the test chamber.

After the specimen and extensometer assembly attained a thermal and mechanically stable state, a three-cycle creep-recovery test as demonstrated in Figure 4, was conducted. Each creep and recovery cycle consisted of a fifteen minute creep loading period and forty-five minute unloaded recovery period. The time duration was approximately ten seconds in applying the dead load to the specimen or relieving the load from the specimen. Deformation and temperature data were recorded on the Gulfton strip chart recorder as shown in Figure 8. This strip recording can reveal the quality of the data at a glance. Any temperature or mechanical disturbance in the course of creep-recovery testing can be easily spotted. This provides a screening device to obtain reliable quality test data.

Tables 7 through 9 summarize the creep-recovery tests conducted. The test results are shown in Figures 11-1 through 11-66. Tables 7 through 9 also con- tain the information description of all the creep-recovery curves in Figures 11-1 through 11-66.

Analysis of the data was conducted primarily for the $(0)_8$ specimens and the $(\pm 45)_{2S}$ specimens. The $(90)_{20}$ data is more susceptible to mechanical disturbance during testing and, hence, the $(90)_{20}$ data is used for reference only. The objective in the data analysis of creep-recovery curves was to find the parameters Do, D, and n values in the power law compliance, equation (5). As discussed in Section 3.1, the exponent n is determined first by data either in the recovery region or in the creep region. After n is determined, the linear regression technique can be used to determine the parameters D_0 and D_1. The best n value can be determined by matching the log ϵ_r versus λ curve to the log $[(1 + \lambda)^n - \lambda^n]$ versus λ curve by vertical shift. The standard log $[(1 + \lambda)^n - \lambda^n]$ versus λ curve is shown in Figure 12 which covers n values from 0.05 to 0.90.

A summary of n values obtained from the test data analysis is shown in Tables 10 and 11. Data in the creep region can be used to obtain not only parameters D_0 and D_1, but also n values. This is accomplished by inserting creep data points into the compliance equation (5) with n values ranging from .02 to .09. Nine data points were selected at time (t) = 0.5, 1, 1.5, 2, 2.5, 3, 5, 10, 15 minutes. With each fixed n value, parameters D_0 and D_1 were obtained through linear regressions. This computation was performed with a computer routine called "CREEP". The best D_0, D_1 and n value should give the least standard deviation value in the linear regression analysis. As

described in Section 3.1, the initial compliance, D_0 is usually an order of magnitude larger than the net creep compliance $D-D_0$. While the CREEP computer program is more sensitive to changes in D_0 value than that of $D-D_0$, it provides an alternate method to check the n values obtained with recovery data.

4.0 CONCLUSIONS AND RECOMMENDATION

The Kevlar/epoxy specimens exhibit a strong dependence on the time, temperature and moisture for both fiber dominated laminates and matrix dominated laminates. This environmental dependence has been characterized through a creep-recovery test method which exhibits its quantitative dependence on environments through the power law compliance representation. In the process of characterizing the composite through creep-recovery testing, several Kevlar 49/5208 characteristics that are unique as compared with glass/epoxy or graphite/epoxy were observed and will be discussed in the following paragraphs. These characteristics will not only help in gaining insight into the Kevlar/epoxy laminate structural performance but will also define directions for future research.

1. Stress dependence: Load levels have an effect on the power law exponent, n, value in both $(0^o)_8$ and $(\pm 45^o)_{2s}$ specimens. Assuming that general polymer creep behavior can be used as a gauge, it is possible to expect the exponent value, n, of Kevlar/epoxy to shift to a larger value at a higher stress level such as 60% to 90% of the ultimate stress level. However, for our tests at lower stress levels such as those indicated in Table 10, the exponent value, n, tends to be higher. This is probably caused by the combination of internal friction and residual stress. This internal friction tends to be related to inherent flaws in the laminate.
2. Longer Mechanical Stabilization: Four quick creep-recovery cycles were exercised to mechanically stabilize the test assembly and the specimen's internal flaws. The three-cycle (one hour per cycle) creep-recovery data indicates a cycle-to-cycle growth of both the creep displacement and the residual initial strain. Apparently four cycles are not sufficient to mechanically stabilize the specimen's internal flaws. It is recommended for future creep-recovery testing of Kevlar/epoxy material, that more than four cycles be used to study the internal structural stability so that the mechanical stabilization of internal Kevlar/epoxy structure can be separated from the material degradation from environmental exposure.

3. Anisotropy of Kevlar fiber: It is still debatable whether the application of the Halpin-Tsai equation to Kevlar 49/5208 composite is a suitable approach. It is believed that Halpin-Tsai equations should be verified for an anisotropic fiber such as Kevlar 49. Since the Kevlar fiber is viscoelastic in itself, its properties should be investigated in order to add to the understanding of its in-situ behavior in the composite. Additional, off-angle type creep-recovery testing is also necessitated in the theoretical characterization of these anisotropic laminates.
4. Long Time Behavior Prediction: One of the advantages of the power law approach (or viscoelastic approach) is to enable the structural designer to utilize the Kevlar/epoxy composite in both short-term (one hour) and long-term (years) applications in structural components by supplying mechanical properties as a function of time. The data from current creep-recovery tests are short term results or are accelerated test results. It is anticipated, but unverified, that these short term results can be used to predict long term behavior. Thus, long-term application of the viscoelastic characterization should be verified.
5. Inherent Flaws: The influence of distributed flaws on the mechanical response of the composite has gained attention in recent years.[7] The cycle to cycle variation during the creep-recovery test on Kevlar 49/5208 also points out the strong possibility of the inter-play of the inherent flaws in the global mechanical response of composites. Recent findings by Schapery[10] provide a rational way to characterize the damage induced mechanical response. It is suggested that strain controlled testing, such as a sawtooth strain history, be conducted to study the effect of inherent flaws on Kevlar/epoxy global response.

TABLE 1 - DEVELOPMENT OF PROCESSING TECHNIQUE FOR NARMCO KEVLAR 49/RIGIDITE 5208 SYSTEM

PANEL DESIGNATION	PANEL SIZE	PRECURE TREATMENT	PROCESS PROCEDURE	QUALITY ANALYSIS
P-1, P-2, P-3, P-4	28"x18"x20 ply	None	A	High Porosity
P-5, P-6	28"x18"x8 ply	None	A	Acceptable
T-1	28"x18"x20 ply	None	C	Panels Dry
T-2	28"x18"x20 ply	None	C	High Porosity
T-3	6"x6"x8 ply	Put Panel into 325°F Oven for 15 Minutes and Check the Weight Loss	-	Lost 2.61% Weight
A-1	6"x6"x8 ply	Put Plies in Dessicator for 93 Hours	C	Acceptable
B-1	6"x6"x8 ply	Plies Out for 24 Hours	C	High Porosity
C-1	6"x6"x8 ply	Plies Out for 96 Hours	C	High Porosity
D-1	6"x6"x8 ply	None	B	Too Much Resin Bleeding
E-1	6"x6"x20 ply	None	B	Too Much Resin Bleeding
M	6"x12"x8 ply $(\pm 45)_{2s}$	Stack Plies Over Bubble Pack and Desiccate for 48 Hours	C	Small Porosity
N	12"x12"x8 ply	Same as M	C	Small Porosity
O	12"x12"x14 ply	Stack Plies over Bubble Pack Desiccate for 6 Days	C	Acceptable
J-1	6"x12"x8 ply	Same as O	C	Acceptable
P	12"x21"x18 ply $(0_2, \pm 45, 90_2, \pm 45, 0)_s$	Same as O	C	Acceptable

A. Narmco Process Procedure with No Bleed, Appendix A
B. Vought Process Specification, Appendix B
C. Same as B with No Bleeding

TABLE 2. COMPOSITE PANELS DESCRIPTION

PANEL ID	LAMINATE	DIMENSION	C-SCAN RESULTS	NO. OF COUPONS CUT FROM THE PANEL
A	$(0)_8$	18" x 20" x .043"	O.K.	61
B	$(\pm 45)_{2s}$	18" x 20" x .046"	O.K.	49
C	$(90)_{20}$	18" x 20" x .118"	O.K.	41
D	$(45)_{20}$	18" x 20" x .113"	O.K.	46
E	$(30)_{20}$	18" x 20" x .120"	O.I.	35

TABLE 3. CREEP-RECOVERY TEST ENVIRONMENTS

SPECIMEN	LOAD LEVEL % OF UTS *	TEMPERATURE (^{o}F)	HUMIDITY (% R.H.)
0^{o}	10,15,20	75	RTH
$\pm 45^{o}$	20,40,60	120	50
90^{o}	25,37.5,50	150	60
		170	95

* Ultimate loads for 0^{o}, $\pm 45^{o}$, and 90^{o} specimens are assumed to be 6000 lbs., 450 lbs, and 300 lbs, respectively

TABLE 4. MOISTURE ABSORPTION ENVIRONMENTS

REL. HUM.	TEMP.	SALT SOL.
RTH	75°F	--
50	170°F	NaBr
60	170°F	KI
95	170°F	NaF

TABLE 5. THERMOMECHANICAL ANALYSIS

ENVIRONMENT	Tg RANGE °C	Tg MIDPOINT °C
Dry	220-275	250
50% RH	154-225	190
95% RH	125-210	170

TABLE 6. STATIC PROPERTIES OF KEVLAR 49/5208 SPECIMEN AT TYPICAL ENVIRONMENTS

SPECIMEN TYPE	SPECIMEN ID	TEST ENVIRONMENT TEMP. (°F)	TEST ENVIRONMENT HUMIDITY (% R.H.)	FAILURE LOAD (LBS)	FAILURE STRESS (PSI)	FAILURE STRAIN (μ in/in)	YOUNG'S MODULUS (MSI)	TEST MEASUREMENT DEVICE
$(0)_8$	4EA-14	75	Dry	-	-	-	10.60	EXTENSOMETER
	4EA-22	75	Dry	-	-	-	10.18	
	A1	75	Dry	5,200	162,105	-	-	MTS MACHINE
	A2	75	Dry	5,300	170,528	-	-	
	4EA-83	120	Dry	5,250	171,878	-	-	
	4EA-56	120	Dry	6,000	183,038	-	-	
$(\pm 45)_{2s}$	4EB-45	75	Dry	490	14,868	32,238	0.971	STRAIN GAGE & EXTENSOMETER
	4EB-60	75	Dry	511	14,812	33,985	0.886	
	4EB-23	120	50	429	12,434	35,408	0.905	SHOREWESTERN MACHINE & EXTENSOMETER
	4EB-34	150	50	398	11,552	39,322	0.879	
	4EB-24	150	50	408	11,827	34,042	0.829	
	4EB-26	170	95	390	11,304	42,326	0.873	
	4EB-52	170	95	385	11,422	34,860	0.855	
$(90)_{20}$	4EC-5	75	Dry	295	3,411	4,746	0.745	STRAIN GAGE
	4EC-42	75	Dry	239	2,778	3,671	0.688	SHOREWESTERN MACHINE & EXTENSOMETER
	4EC-35	120	50	200	2,244	3,761	0.637	
	4EC-43	120	50	167	1,953	3,044	0.639	
	4EC-53	150	50	139	1,586	2,633	0.594	
	4EC-65	150	50	207	2,319	3,904	0.590	
	4EC-36	170	95	61	690	1,576	0.392	

TABLE 7. DESCRIPTION OF CREEP-RECOVERY CURVES OF $(0)_8$ SPECIMENS IN FIGURES 11-1 TO 11-12

FIGURE	SPECIMEN ID	TEST ENVIRONMENT		CREEP STRESS LEVEL (PSI)	DEFORMATION (10^{-6} in/in/Division)
		TEMPERATURE (^{o}F)	HUMIDITY (% R.H.)		
11-1	4EA-14	75	Dry	18,255	89.6
11-2	4EA-14	120	Dry	18,255	89.6
11-3	4EA-14	150	Dry	18,255	89.6
11-4	4EA-14	170	Dry	18,255	89.6
11-5	4EA-22	75	Dry	28,648	89.6
11-6	4EA-22	120	Dry	28,648	89.6
11-7	4EA-22	150	Dry	28,648	89.6
11-8	4EA-22	170	Dry	28,648	89.6
11-9	4EA-64	75	Dry	37,359	89.6
11-10	4EA-64	120	Dry	37,359	89.6
11-11	4EA-64	150	Dry	37,359	89.6
11-12	4EA-64	170	Dry	37,359	89.6

TABLE 8. DESCRIPTION OF CREEP-RECOVERY CURVES OF ($\pm45_{2s}$) SPECIMENS IN FIGURES 11-13 TO 11-54

FIGURE	SPECIMEN ID	TEST ENVIRONMENT		CREEP STRESS LEVEL (PSI)	DEFORMATION (10^{-6} in/in/Division)
		TEMPERATURE (°F)	HUMIDITY (% R.H.)		
11-13	4EB-15	75	Dry	2,612	89.6
11-14	4EB-15	120	Dry	2,612	89.6
11-15	4EB-15	150	Dry	2,612	89.6
11-16	4EB-15	170	Dry	2,612	89.6
11-17	4EB-86	75	Dry	5,340	179.1
11-18	4EB-86	120	Dry	5,340	179.1
11-19	4EB-86	150	Dry	5,340	179.1
11-20	4EB-86	170	Dry	5,340	179.1
11-21	4EB-41	75	Dry	8,011	447.8
11-22	4EB-41	120	Dry	8,011	447.8
11-23	4EB-41	150	Dry	8,011	447.8
11-24	4EB-41	170	Dry	8,011	447.8
11-25	4EB-72	75	50	2,612	89.6
11-26	4EB-72	120	50	2,612	89.6
11-27	4EB-31	150	50	2,666	89.6
11-28	4EB-31	170	50	2,666	89.6
11-29	4EB-35	75	50	5,106	179.1
11-30	4EB-35	120	50	5,106	179.1
11-31	4EB-35	150	50	5,106	179.1
11-32	4EB-35	170	50	5,106	179.1
11-33	4EB-61	75	50	7,826	447.8
11-34	4EB-61	120	50	7,826	447.8
11-35	4EB-31	75	60	2,667	89.6
11-36	4EB-42	120	60	2,670	89.6
11-37	4EB-42	150	60	2,670	89.6
11-38	4EB-42	170	60	2,670	89.6
11-39	4EB-35	75	60	5,106	179.1
11-40	4EB-21	120	60	5,305	179.1
11-41	4EB-21	150	60	5,305	179.1
11-42	4EB-21	170	60	5,305	179.1

TABLE 8. DESCRIPTION OF CREEP-RECOVERY CURVES OF $(\pm 45)_{2s}$ SPECIMEN (concluded)

FIGURE	SPECIMEN ID	TEST ENVIRONMENT		CREEP STRESS LEVEL (PSI)	DEFORMATION
		TEMPERATURE (°F)	HUMIDITY (% R.H.)		(10^{-6} in/in/Division)
11-43	4EB-21	75	60	7,958	447.8
11-44	4EB-21	120	60	7,958	447.8
11-45	4EB-65	75	95	2,612	89.6
11-46	4EB-65	120	95	2,612	89.6
11-47	4EB-65	150	95	2,612	89.6
11-48	4EB-65	170	95	2,612	89.6
11-49	4EB-85	75	95	5,348	179.1
11-50	4EB-85	120	95	5,348	179.1
11-51	4EB-85	150	95	5,348	179.1
11-52	4EB-85	170	95	5,348	179.1
11-53	4EB-64	75	95	7,847	447.8
11-54	4EB-64	120	95	7,847	647.8

TABLE 9. DESCRIPTION OF CREEP-RECOVERY CURVES OF $(90)_{20}$ SPECIMENS IN FIGURES 11-55 TO 11-66

FIGURE	SPECIMEN ID	TEST ENVIRONMENT		CREEP STRESS LEVEL (PSI)	DEFORMATION
		TEMPERATURE (^oF)	HUMIDITY (% R.H.)		(10^{-6} in/in/Division)
11-55	4EC-56	75	Dry	857	89.6
11-56	4EC-56	120	Dry	857	89.6
11-57	4EC-56	150	Dry	875	89.6
11-58	4EC-56	170	Dry	875	89.6
11-59	4EC-16	75	Dry	1,285	89.6
11-60	4EC-16	120	Dry	1,285	89.6
11-61	4EC-16	150	Dry	1,285	89.6
11-62	4EC-16	170	Dry	1,285	89.6
11-63	4EC-62	75	Dry	1,714	89.6
11-64	4EC-62	120	Dry	1,714	89.6
11-65	4EC-62	150	Dry	1,714	89.6
11-66	4EC-62	170	Dry	1,714	89.6

TABLE 10 POWER LAW EXPONENT OF $(0)_8$ SPECIMEN FROM CREEP-RECOVERY TEST

HUMIDITY (% R.H.)	TEMPERATURE (^{o}F)	LOAD LEVEL 1 600 LB (10% UTS)			LOAD LEVEL 2 900 LB (15% UTS)			LOAD LEVEL 3 1200 LB (20% UTS)		
DRY	75	-	-	-	-	-	-	0.05	0.03	0.03
	120	0.5	0.05	0.05	-	-	-	0.10	0.03	0.03
	150	0.3	0.05	0.05	0.15	0.03	0.03	-	-	-
	170	0.05	0.05	0.03	-	-	-	-	-	-
50	75									
	120									
	150									
	170									
60	75									
	120									
	150									
	170									
95	75									
	120									
	150									
	170									

TABLE 11 POWER LAW EXPONENT OF $(\pm 45)_{2s}$ SPECIMEN FROM CREEP-RECOVERY TEST

HUMIDITY (% R.H.)	TEMPERATURE (^{o}F)	LOAD LEVEL 1 90 LB (20% UTS)			LOAD LEVEL 2 180 LB (40% UTS)			LOAD LEVEL 3 270 LB (60% UTS)		
DRY	75	0.13	0.06	0.07	-	0.08	0.07	-	0.08	0.03
	120	0.10	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
	150	0.12	0.10	0.10	-	0.06	0.03	-	-	-
	170	0.12	0.08	0.04	0.05	0.04	0.03	-	-	-
50	75	-	-	-	0.06	0.04	0.04	0.03	0.03	0.03
	120	-	-	-	0.03	0.03	0.03	0.03	0.03	0.03
	150	0.10	0.04	0.03	0.03	0.03	0.03	-	-	-
	170	0.04	0.03	0.03	-	-	-	-	-	-
60	75	0.20	-	0.05	0.03	0.03	0.03	0.03	0.03	0.03
	120	-	-	-	0.04	0.03	0.03	0.03	0.03	0.03
	150	0.08	0.03	0.03	0.04	0.03	0.03			
	170	0.04	0.03	0.03	0.03	0.03	0.03			
95	75									
	120									
	150									
	170									

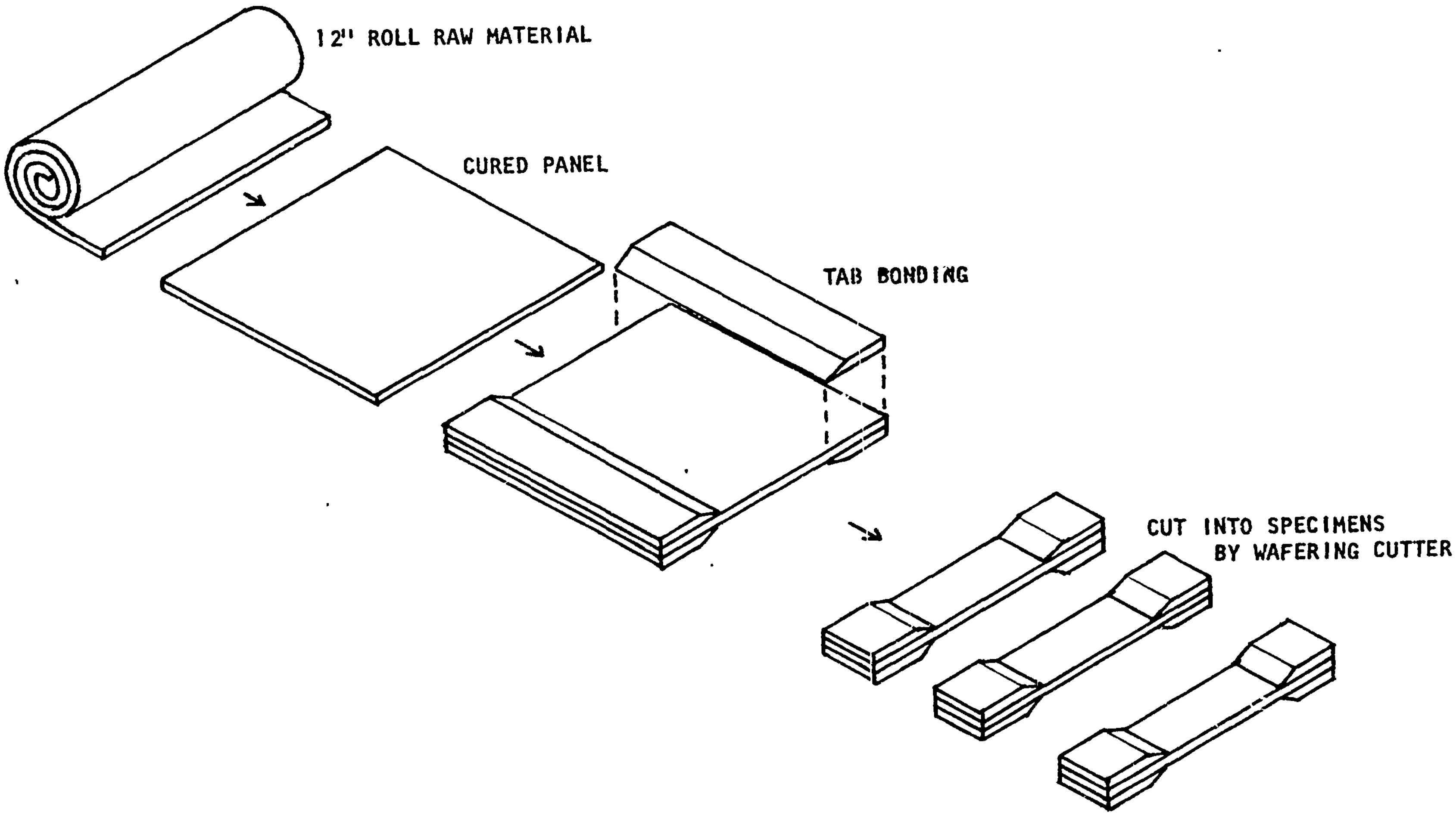
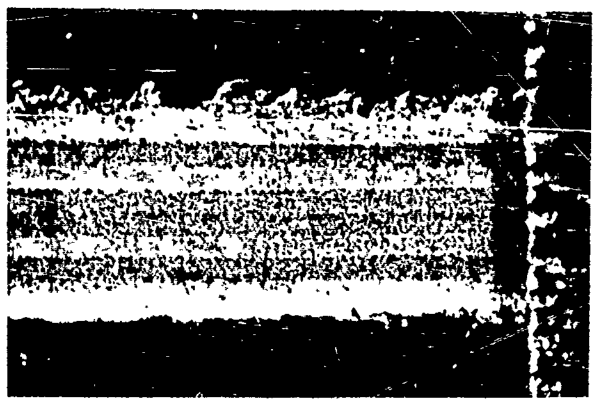
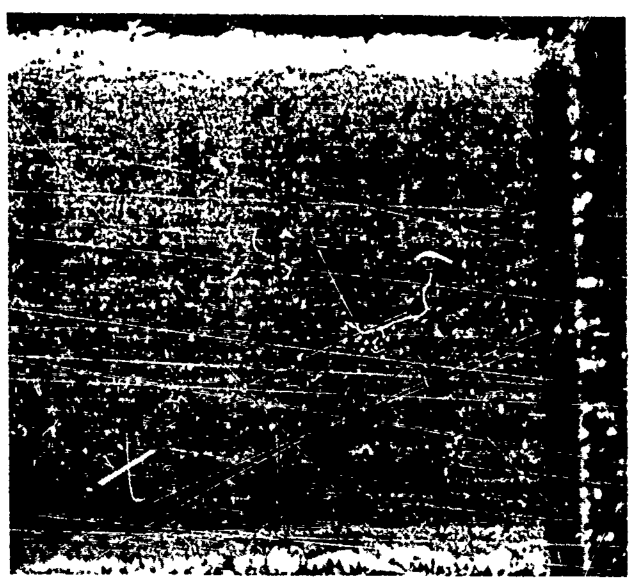


FIGURE 1. SPECIMEN FABRICATION PROCEDURE

2.a. $(0)_8$ SPECIMEN EDGE AT 25 x MICROSCOPE

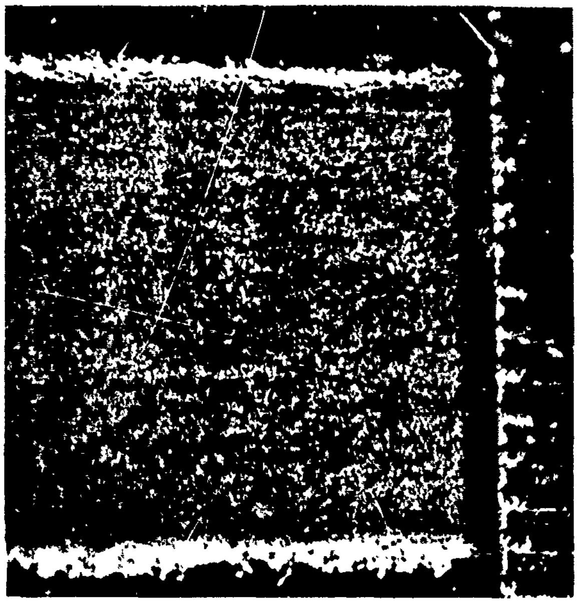


2 b. $(\pm45)_{2s}$ SPECIMEN EDGE AT 25 x MICROSCOPE



2 c. $(90)_{20}$ SPECIMEN EDGE AT 25 x MICROSCOPE

FIGURE 2. EDGE SURFACES FROM WAFERING CUTTER CUT



2d. $(45)_{20}$ SPECIMEN EDGE AT

25 x MICROSCOPE

2e. $(30)_{20}$ SPECIMEN EDGE AT

25 x MICROSCOPE

FIGURE 2 (Cont'd) EDGE SURFACES FROM WAFERING CUTTER CUT

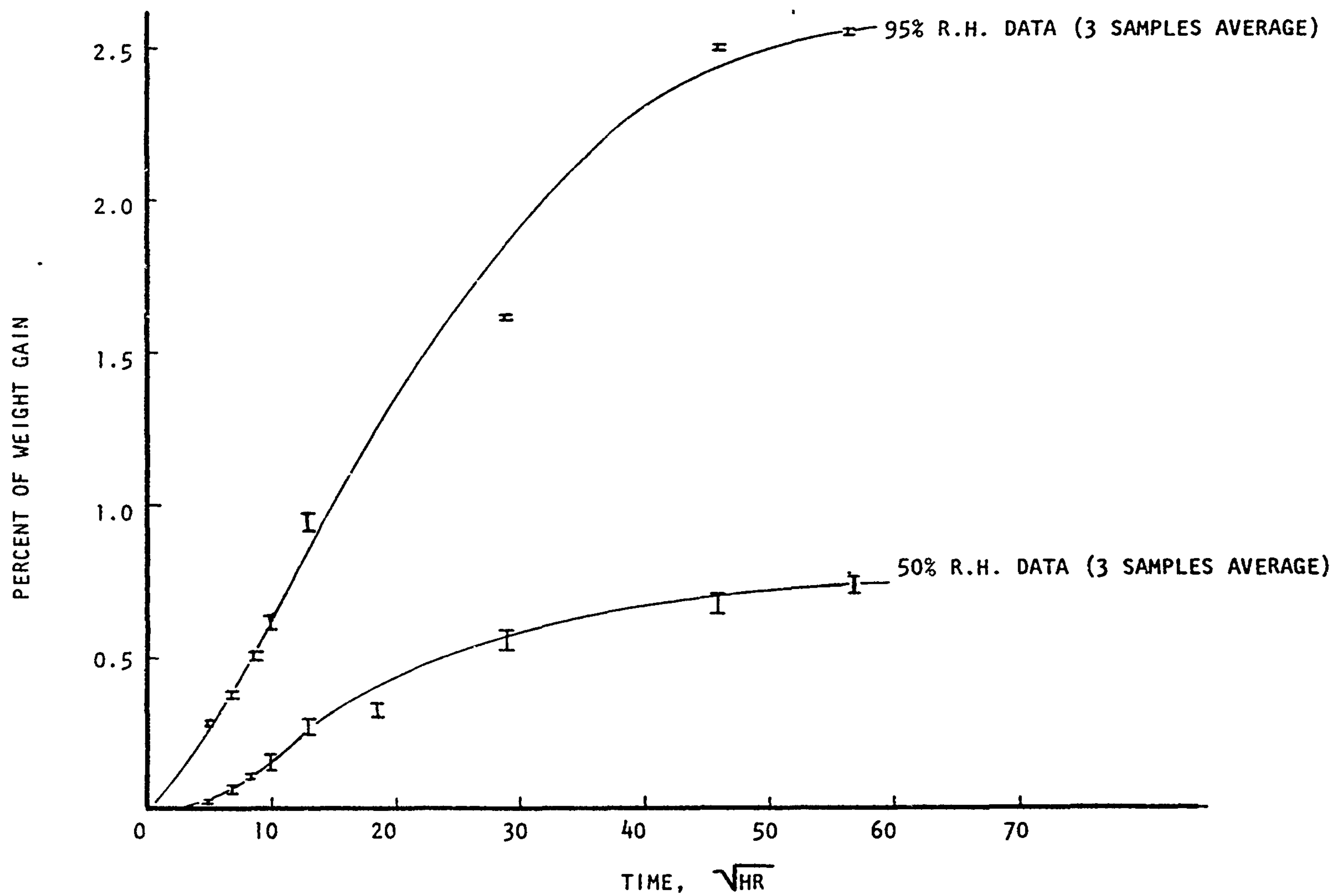


FIGURE 3. MOISTURE ABSORPTION RATE AT 170°F ENVIRONMENT

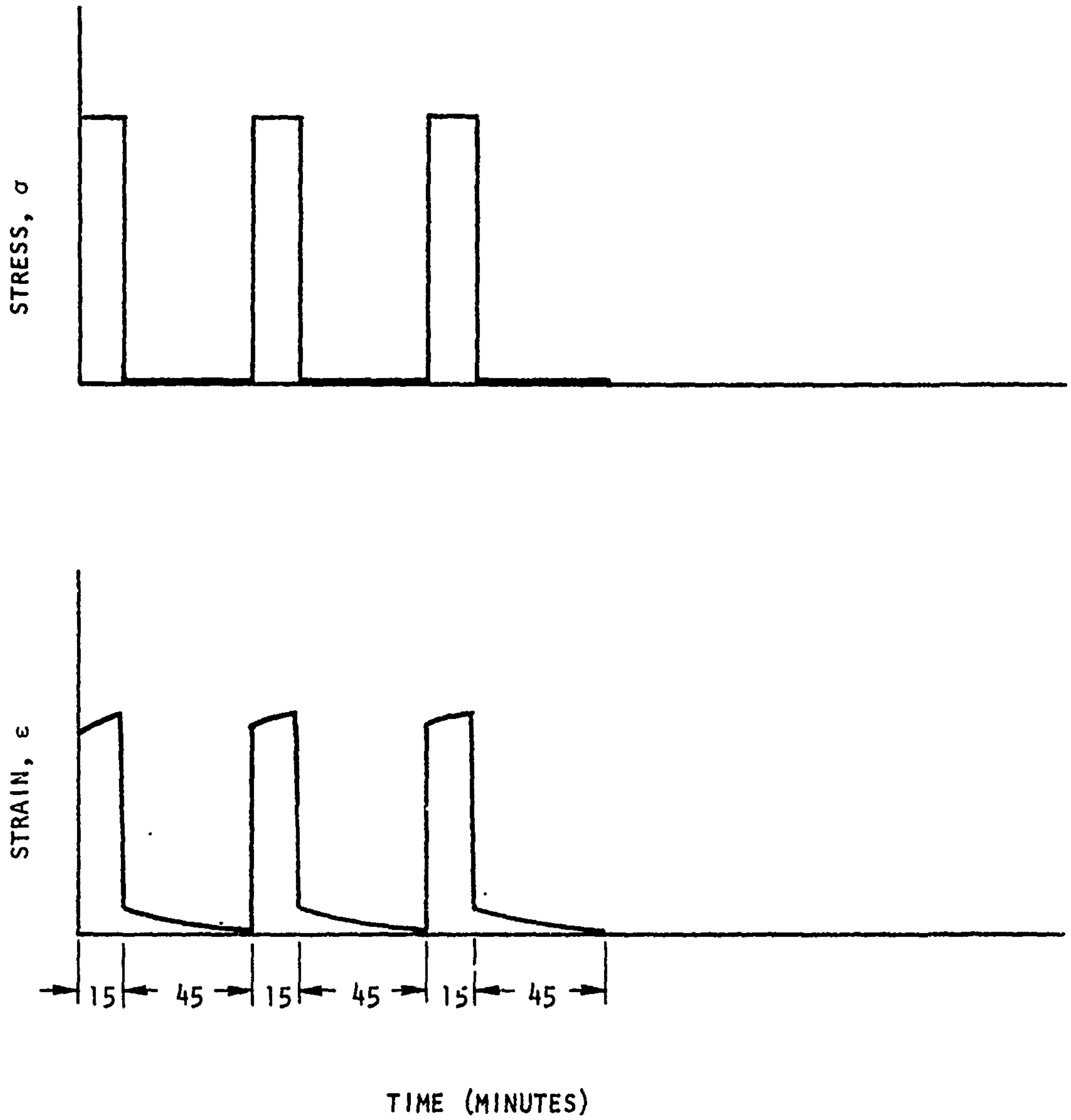


FIGURE 4. CREEP-RECOVERY TEST OF VISCOELASTIC MATERIAL.

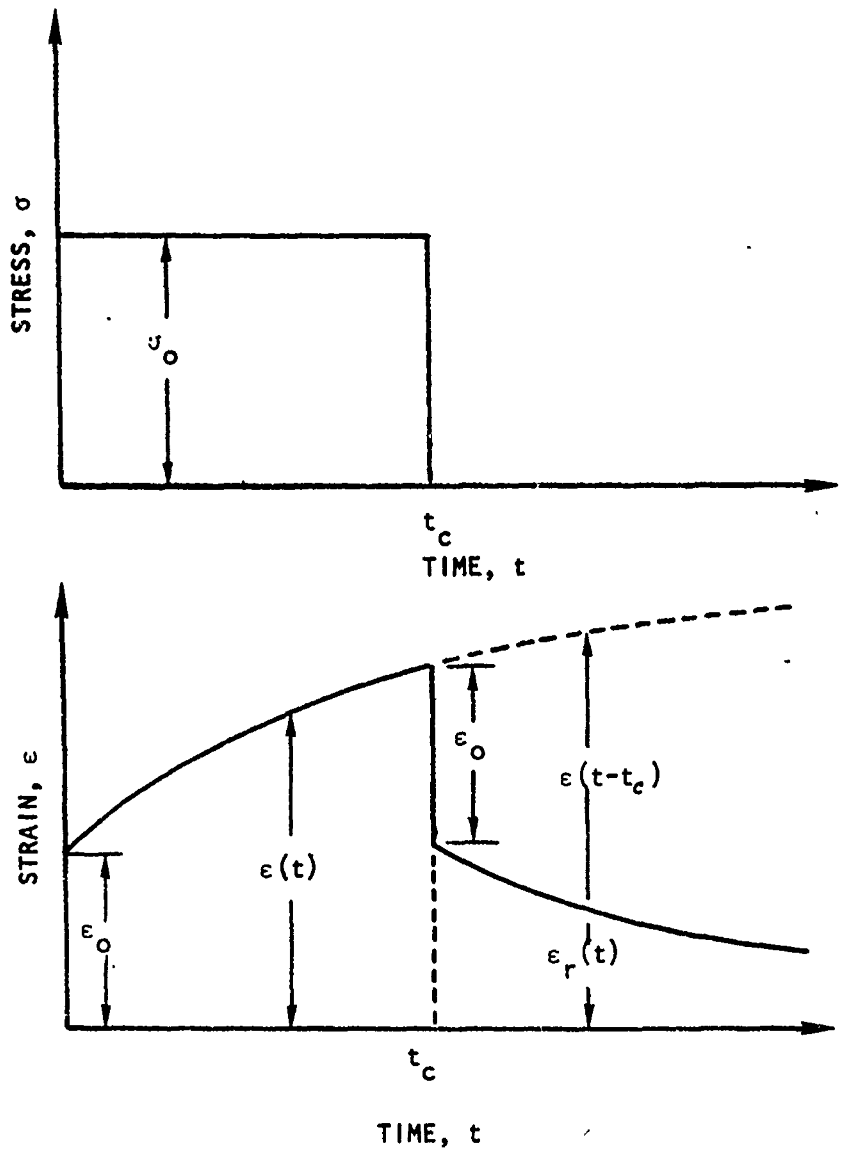


FIGURE 5. RELATION BETWEEN CREEP AND RECOVERY OF A LINEAR VISCOELASTIC MATERIAL.

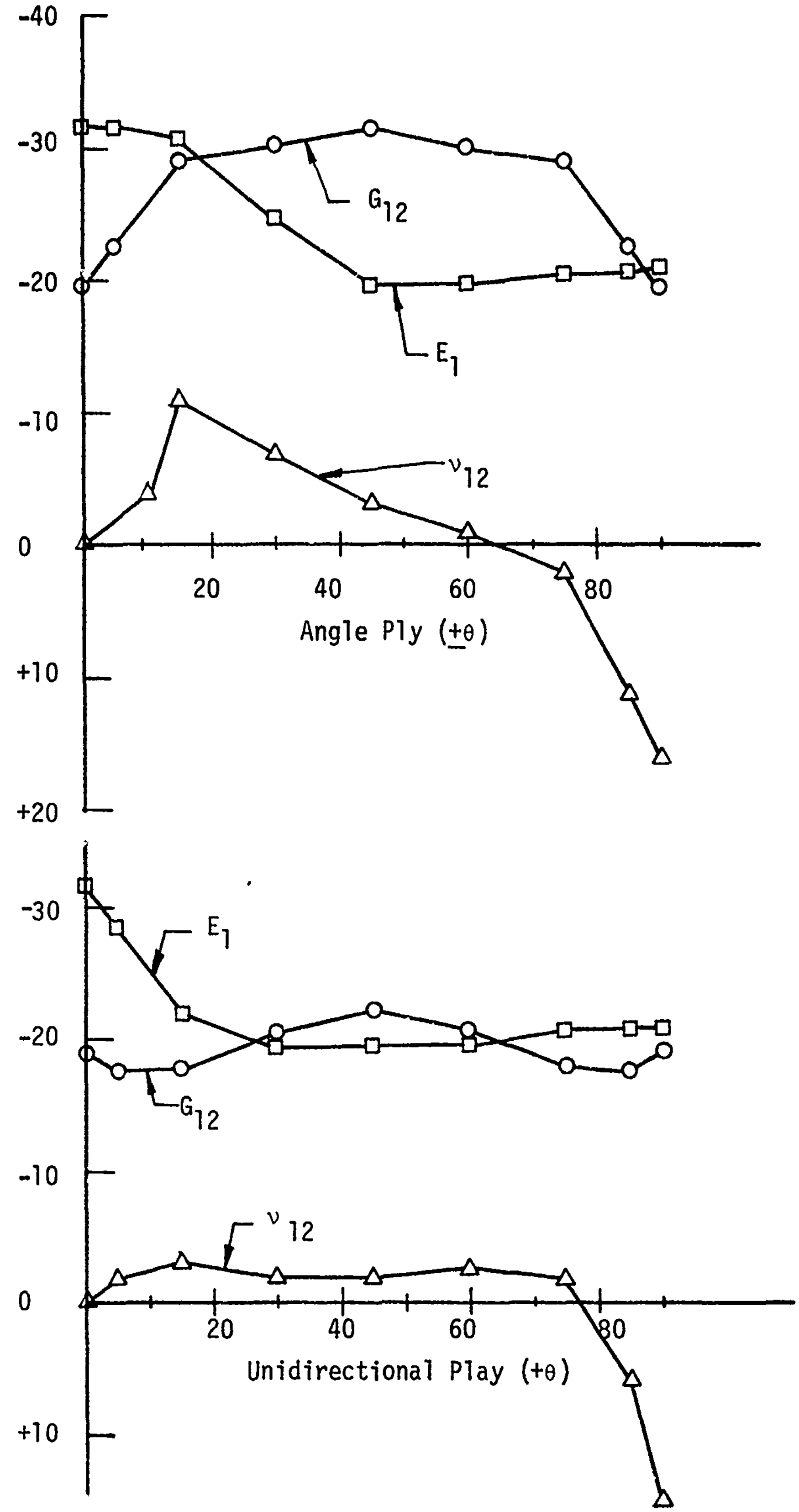
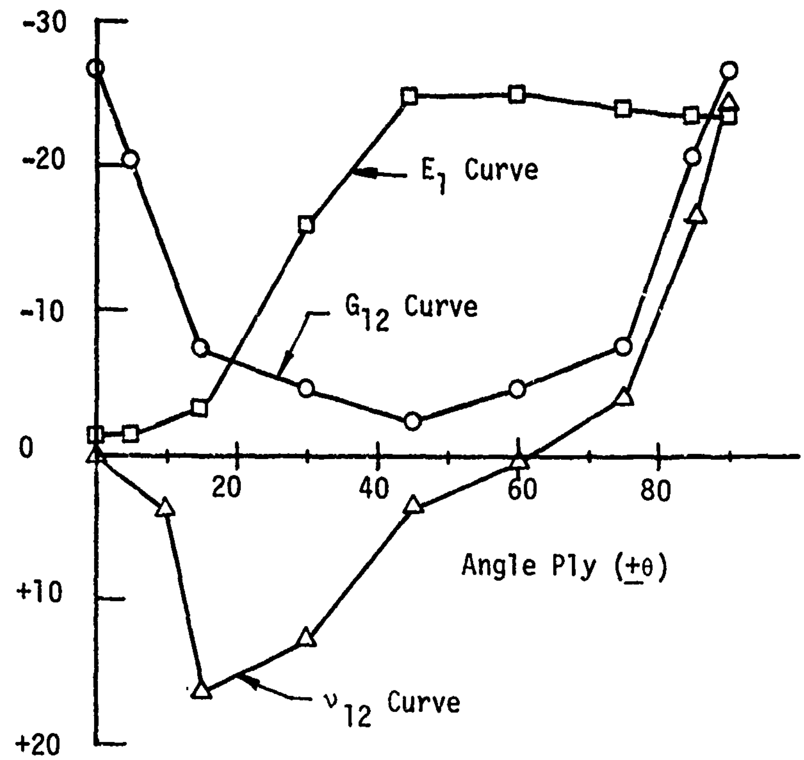


FIGURE 6. LAMINATE PROPERTY CHANGE AS A RESULT OF 17% REDUCTION IN FIBER PROPERTY



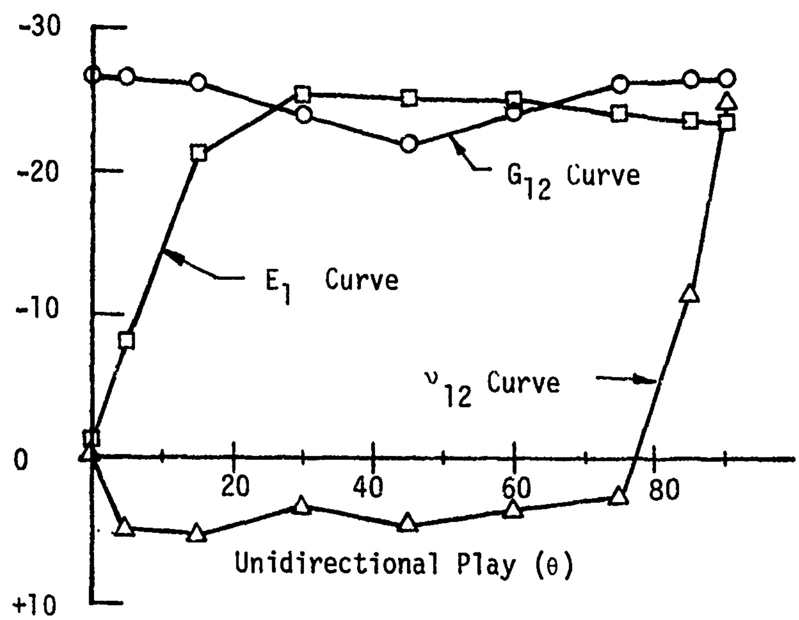


FIGURE 7. LAMINATE PROPERTY CHANGES AS A RESULT OF 50% REDUCTION IN MATRIX PROPERTY

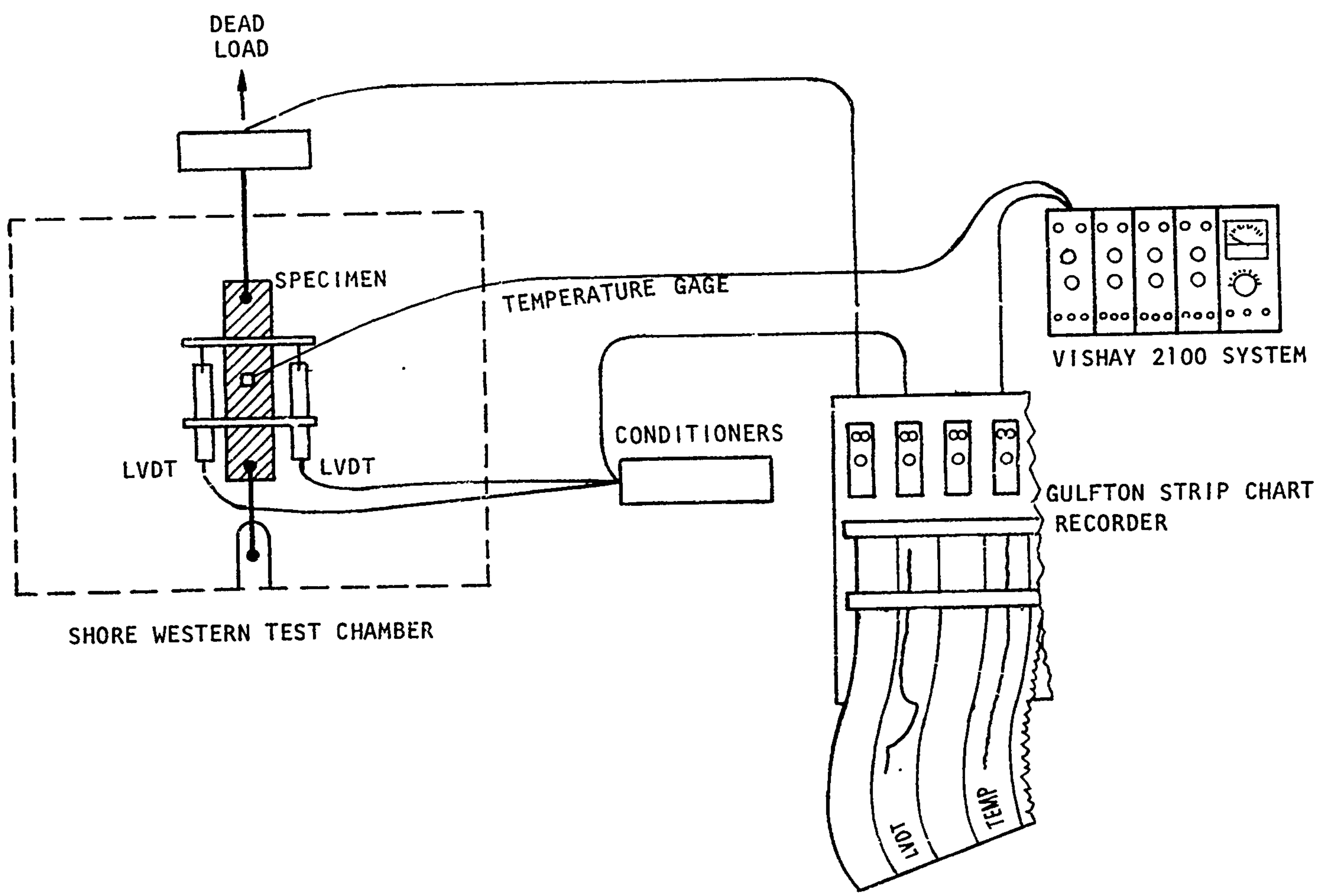


FIGURE 8. CREEP-RECOVERY TEST ARRANGEMENT AND DATA ACQUISITION SYSTEM

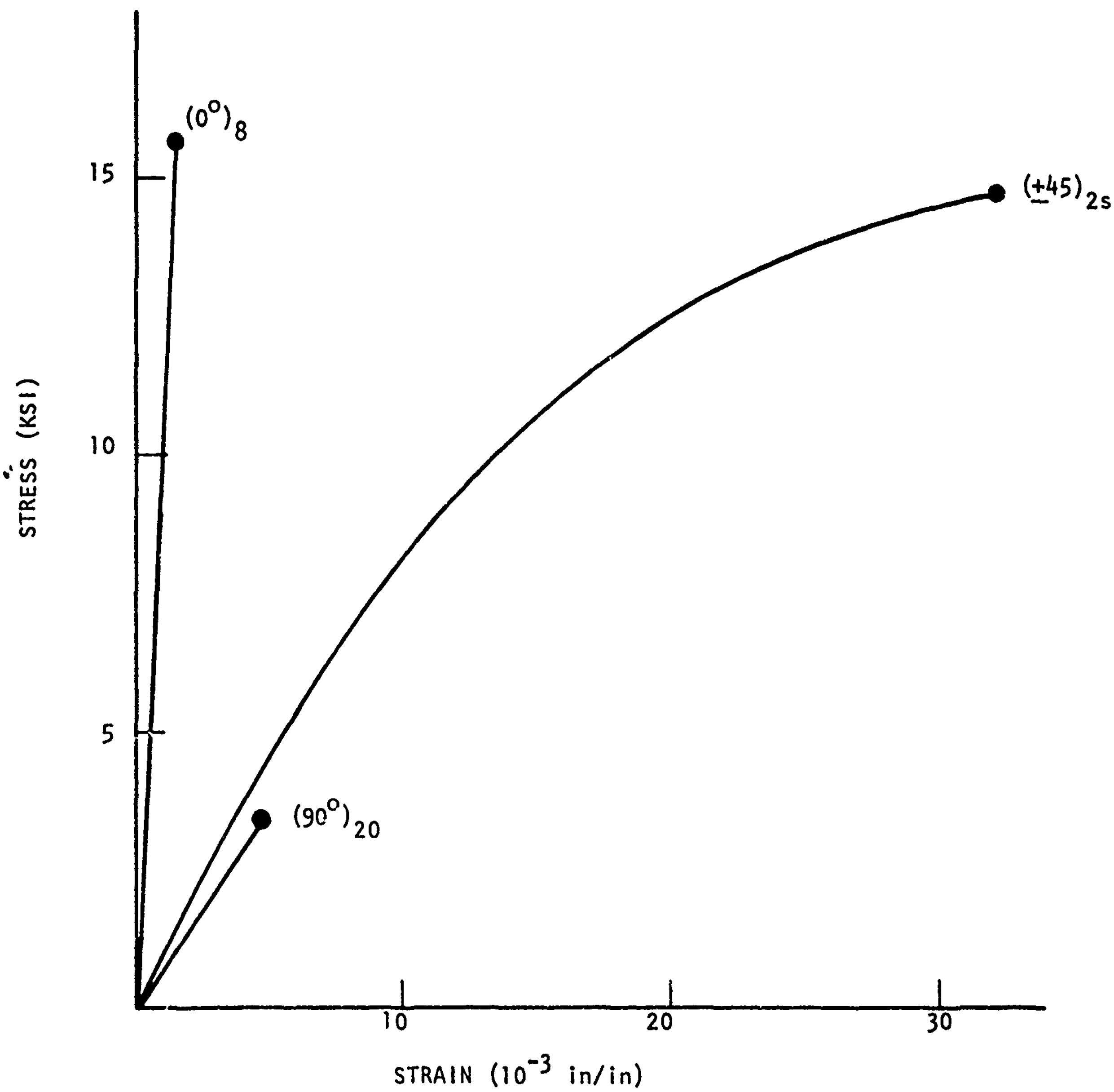


FIGURE 9. TYPICAL STRESS-STRAIN CURVE OF UNIDIRECTIONAL KEVLAR 49/5208 COMPOSITE

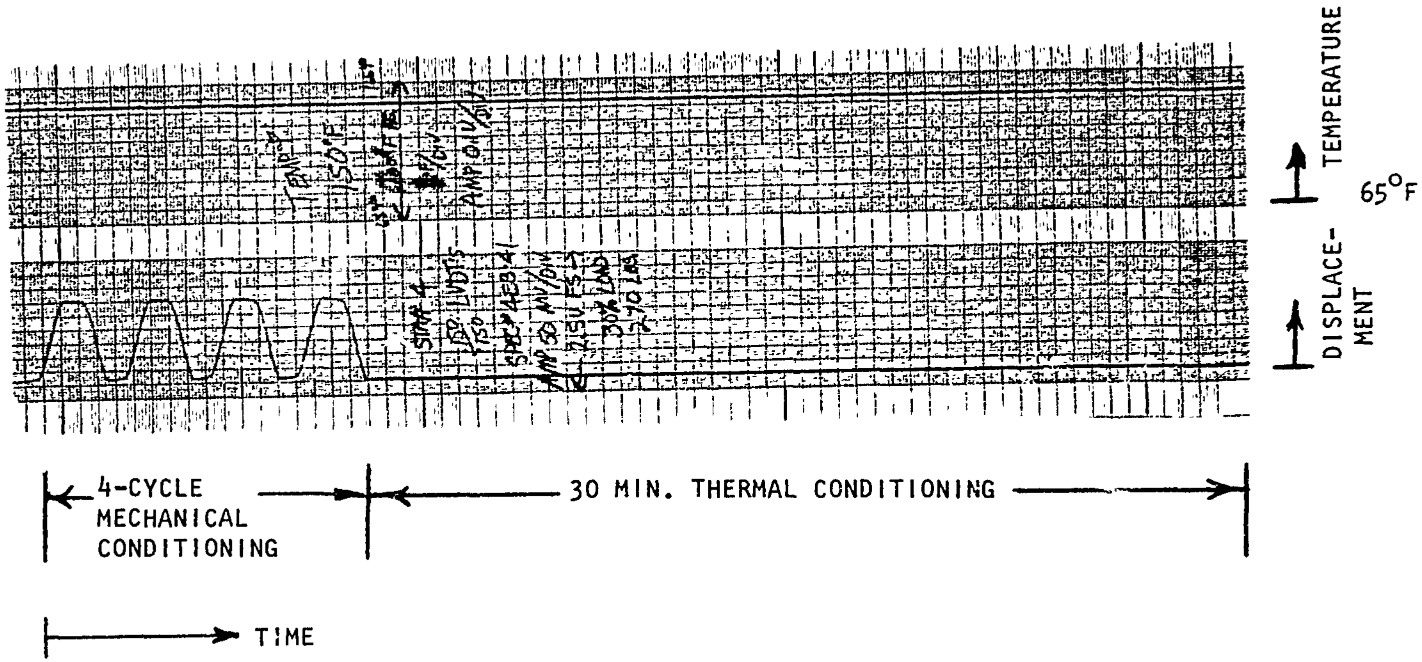


FIGURE 10. TYPICAL THERMAL CONDITIONING AND MECHANICAL CONDITIONING PRIOR TO CREEP-RECOVERY TEST

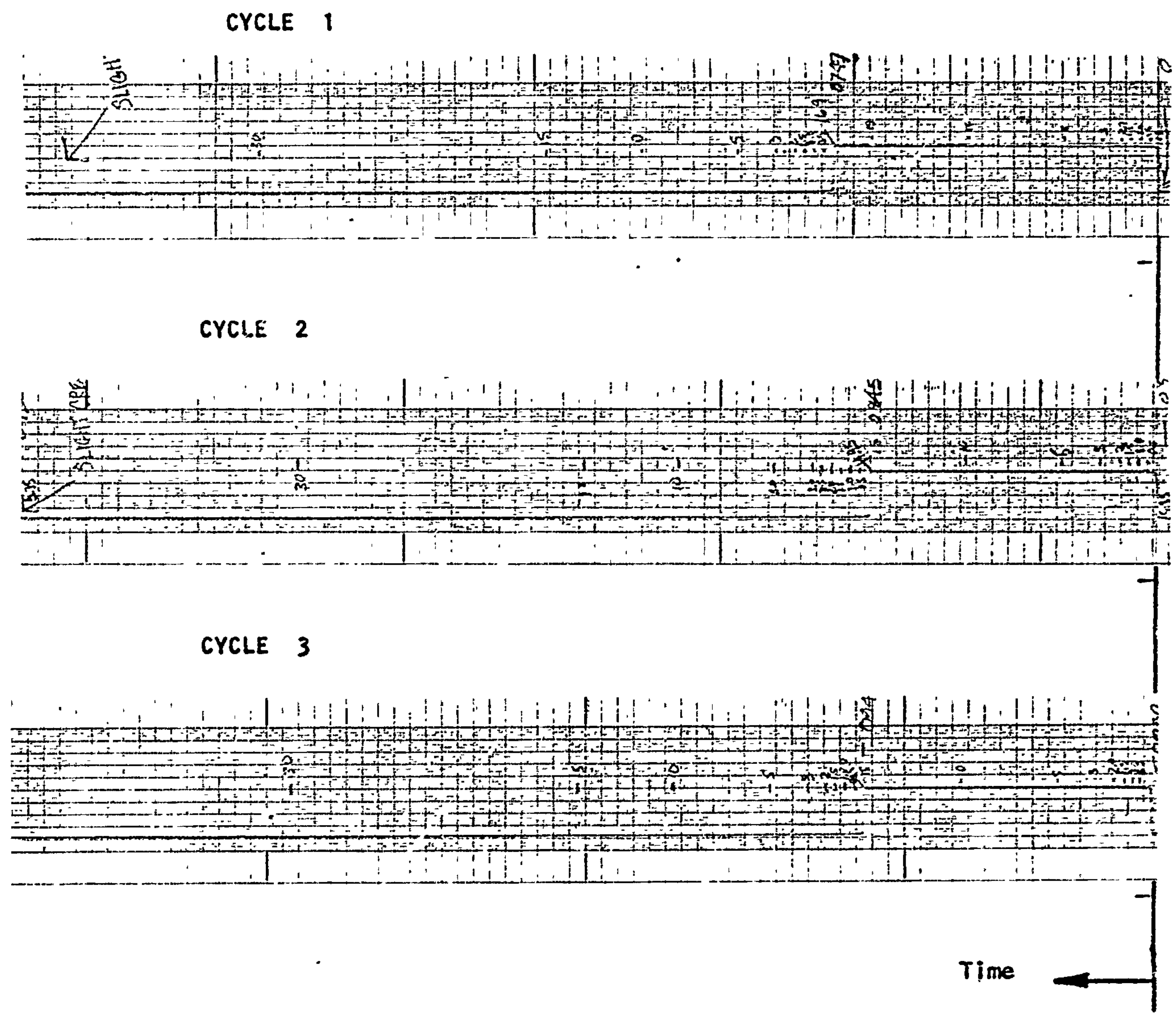


FIGURE 11-1 CREEP-RECOVERY CURVES FOR 0^{o} SPECIMENS AT 75 ^{o}F/dry% RH ENVIRONMENT AND 10% ULTIMATE LOAD LEVEL

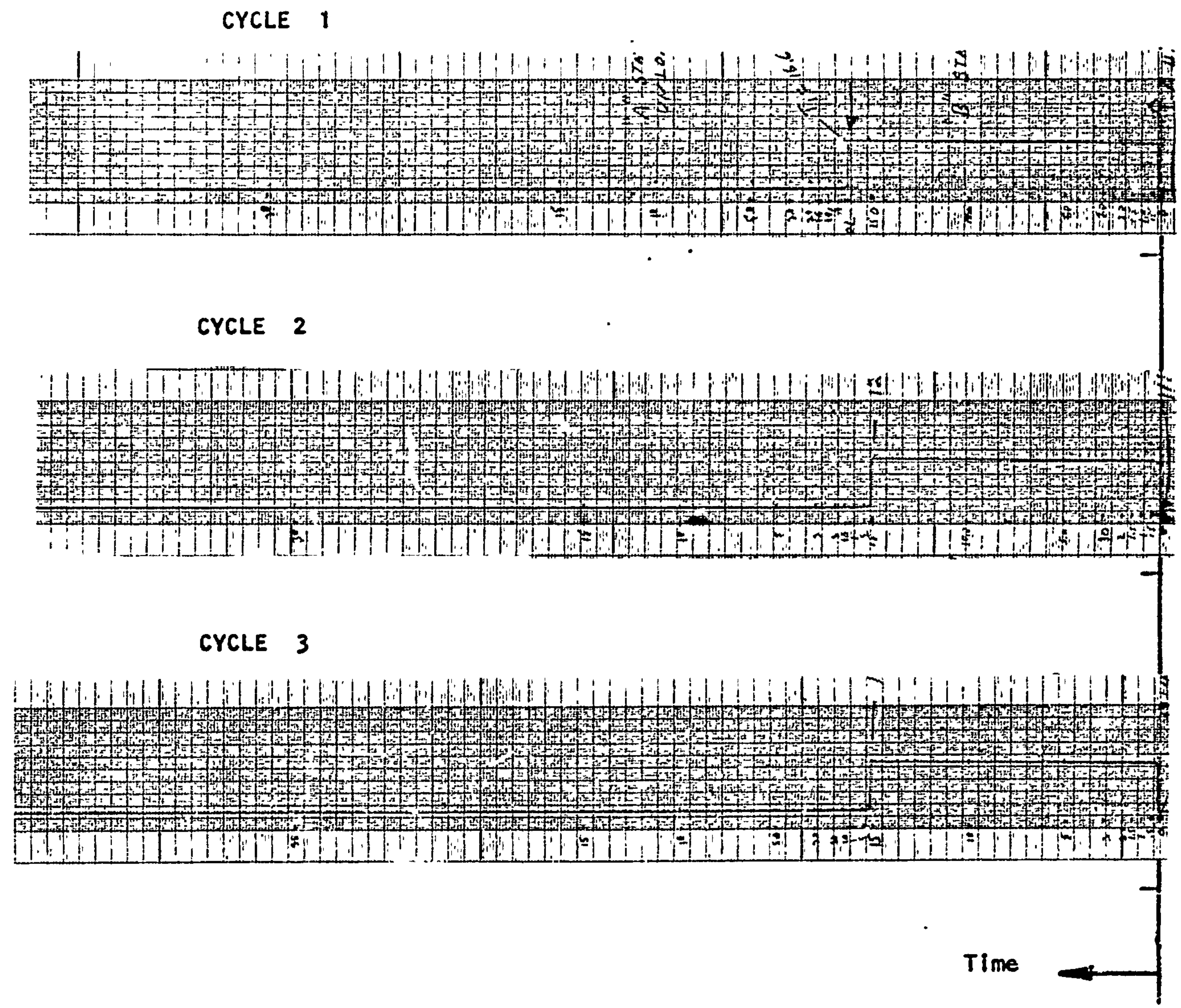


FIGURE 11-2 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 120 °F/ dry% RH
ENVIRONMENT AND 10 % ULTIMATE LOAD LEVEL

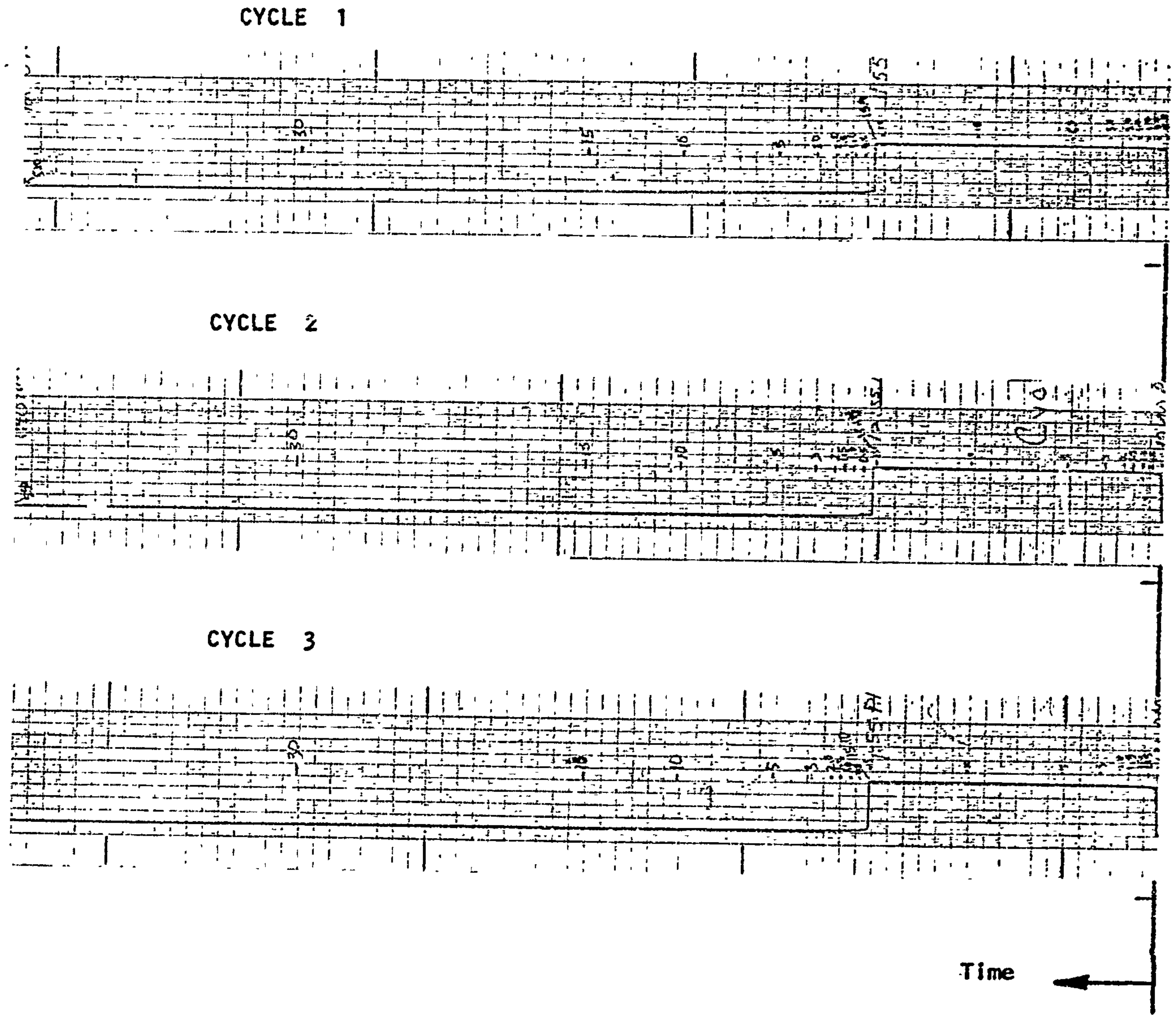


FIGURE II-3 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 150 °F/dry% RH ENVIRONMENT AND 10 % ULTIMATE LOAD LEVEL

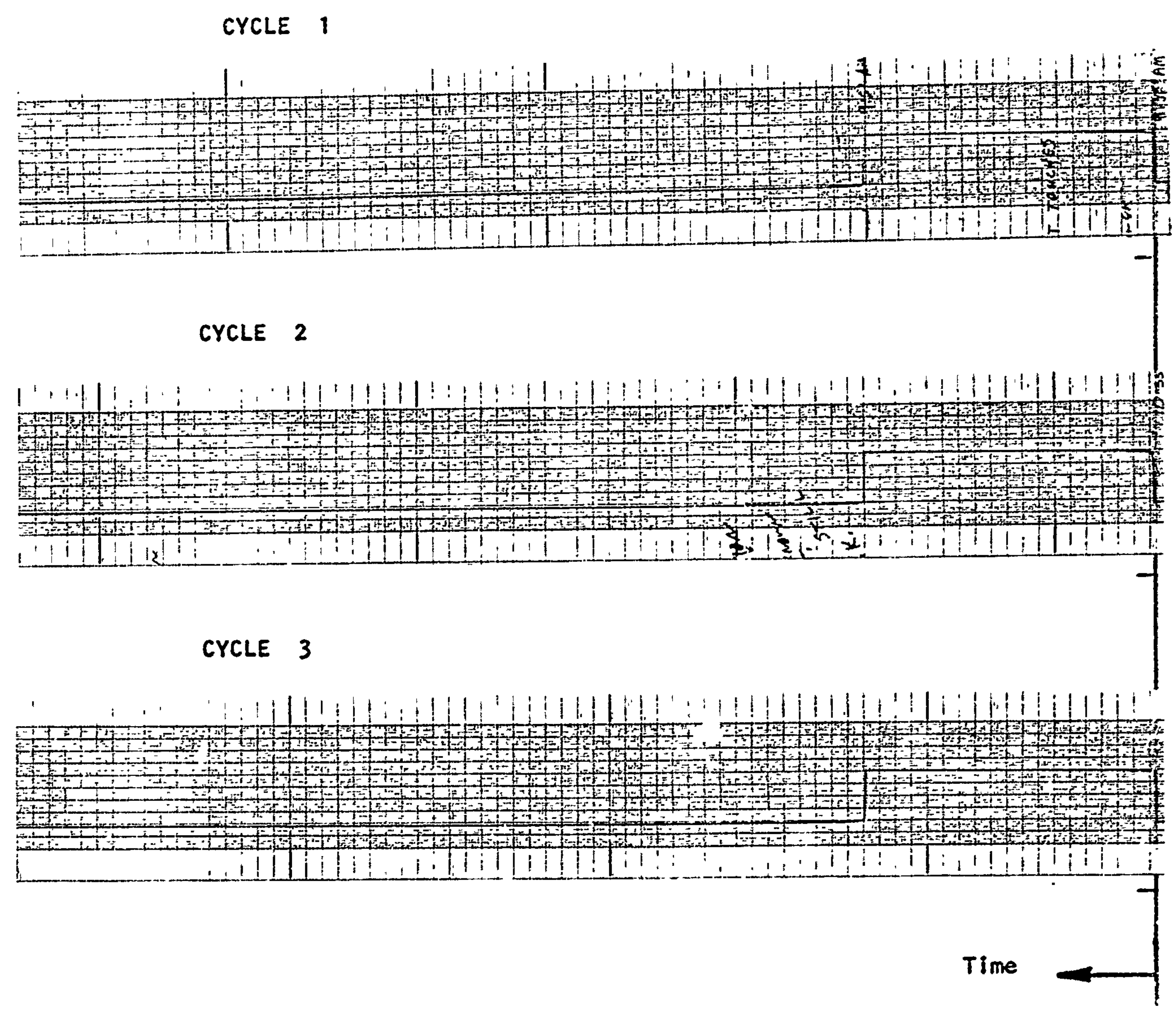


FIGURE II-4 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 170 °F/dry% RH ENVIRONMENT AND 10 % ULTIMATE LOAD LEVEL

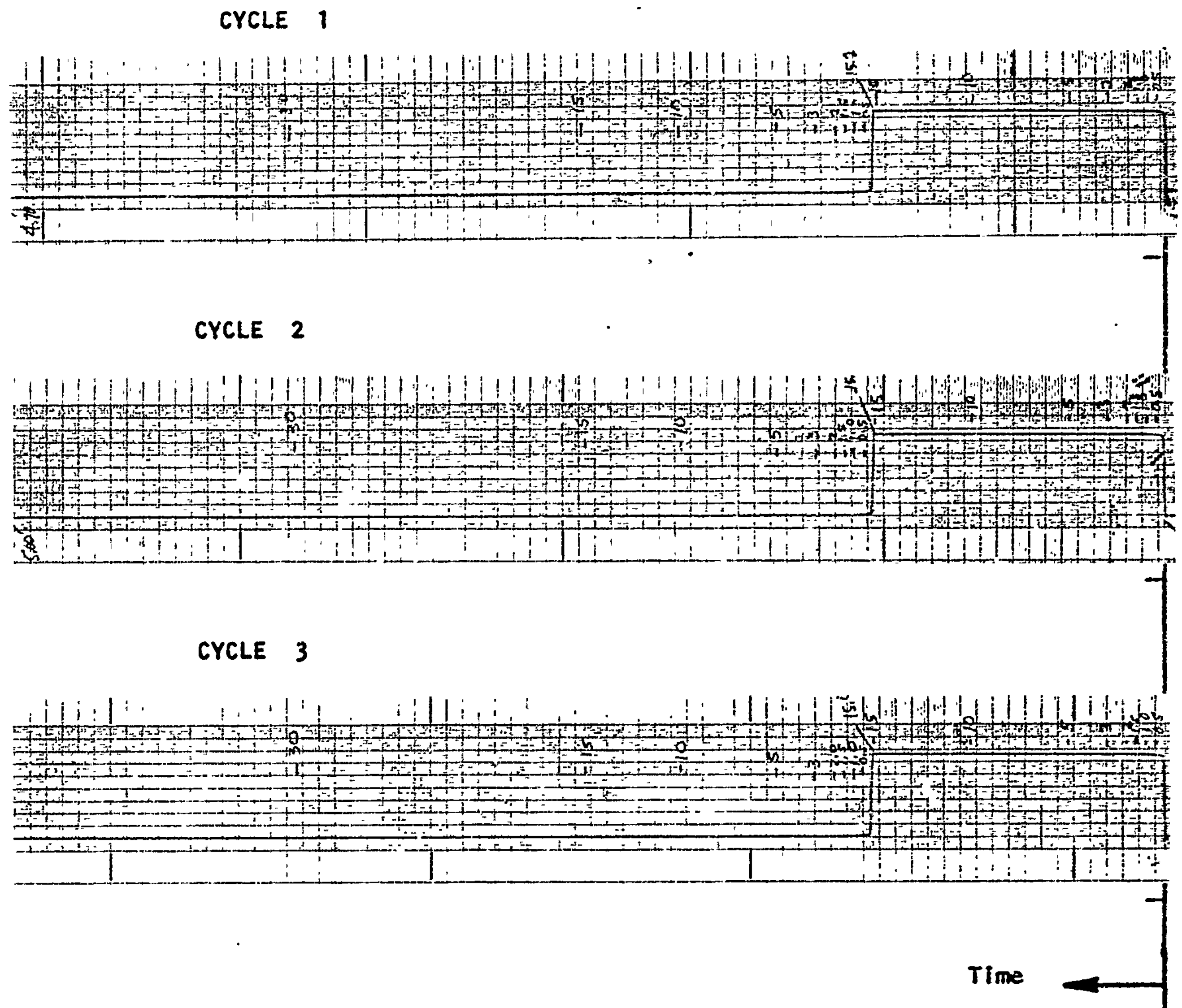


FIGURE II-5 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 75 °F/dry% RH ENVIRONMENT AND 15% ULTIMATE LOAD LEVEL

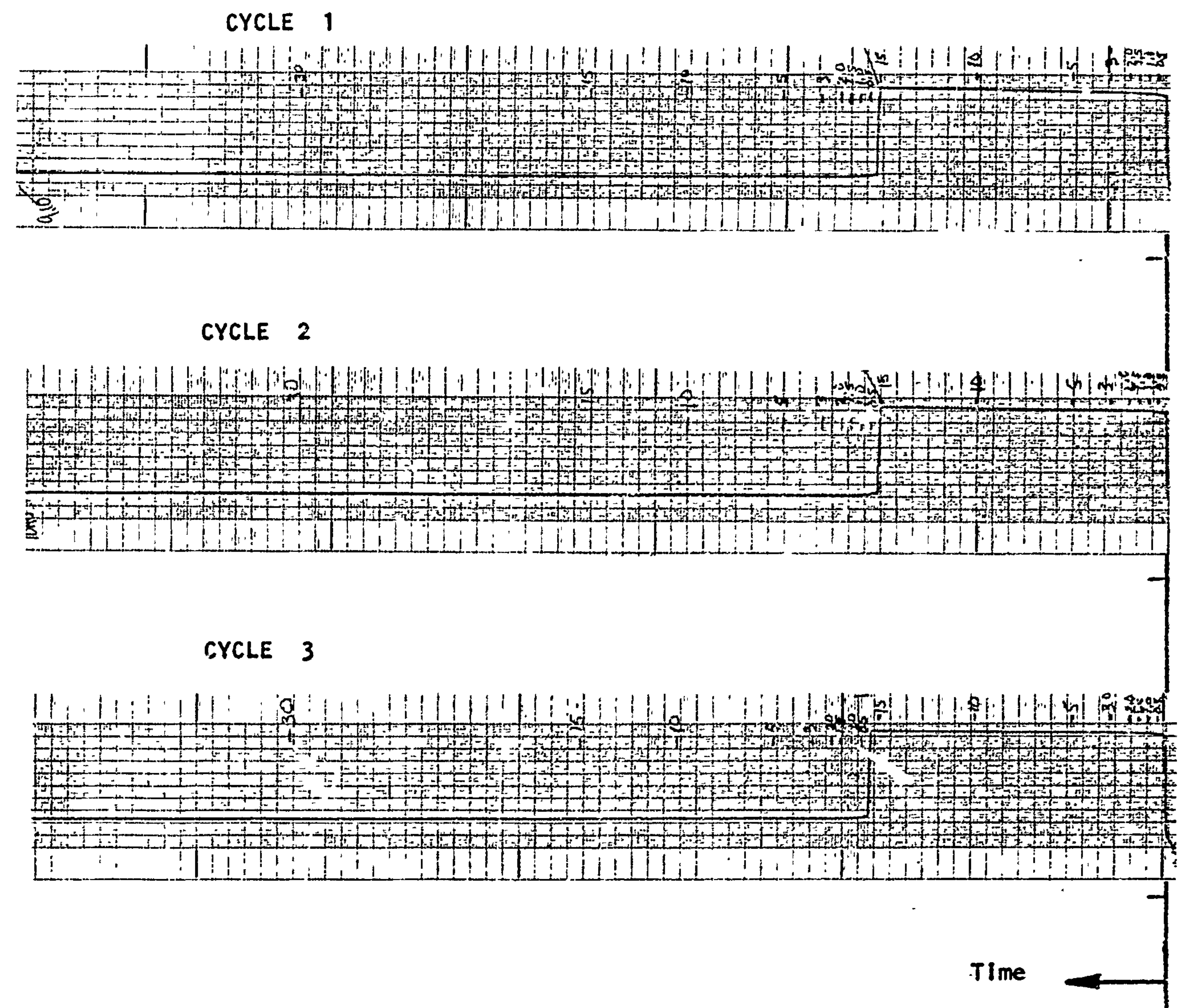


FIGURE 11-6 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 120 °F/dry% RH ENVIRONMENT AND 15 % ULTIMATE LOAD LEVEL

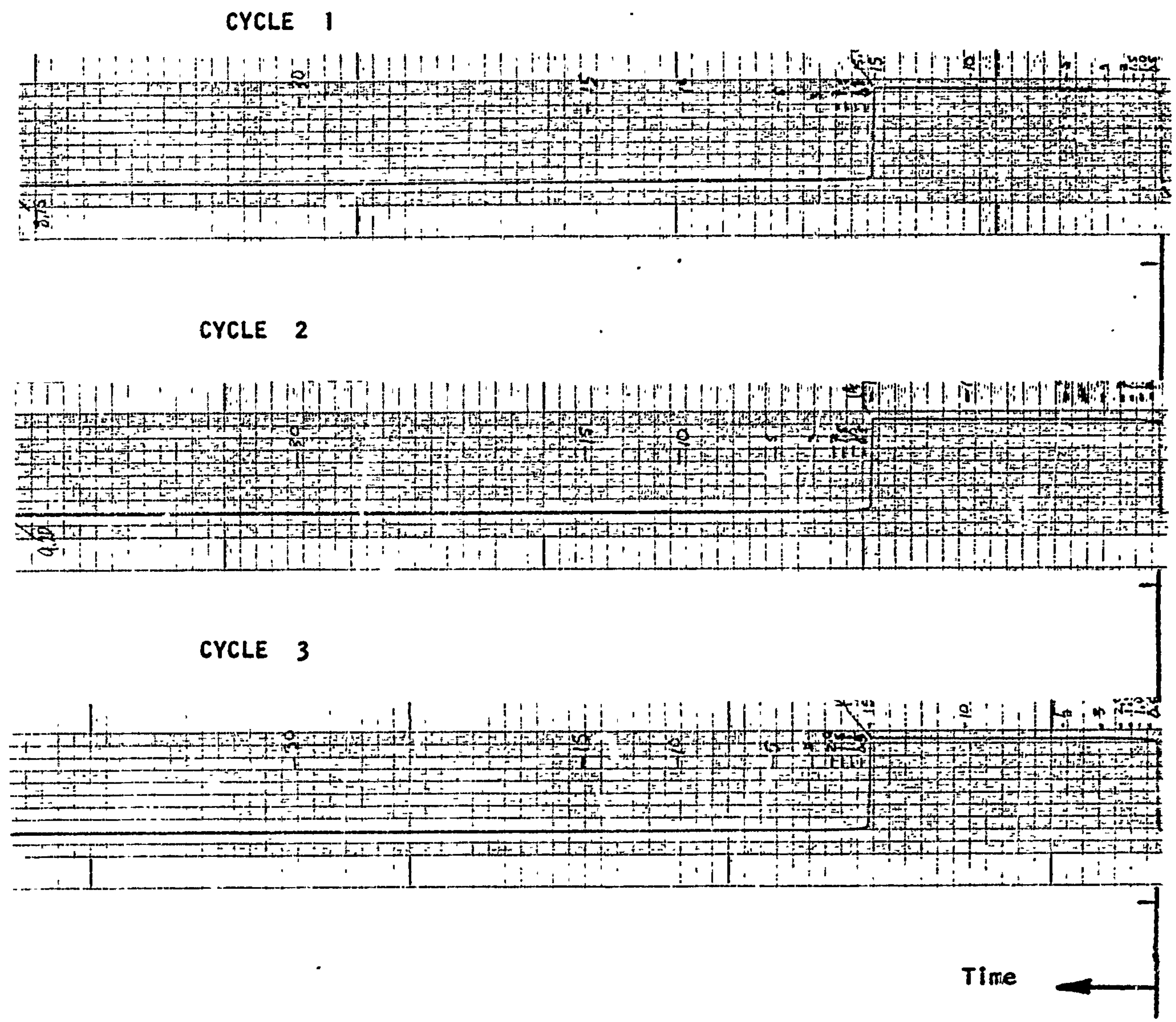


FIGURE 11-7 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 150 $^{\circ}$F/dry% RH ENVIRONMENT AND 15 % ULTIMATE LOAD LEVEL

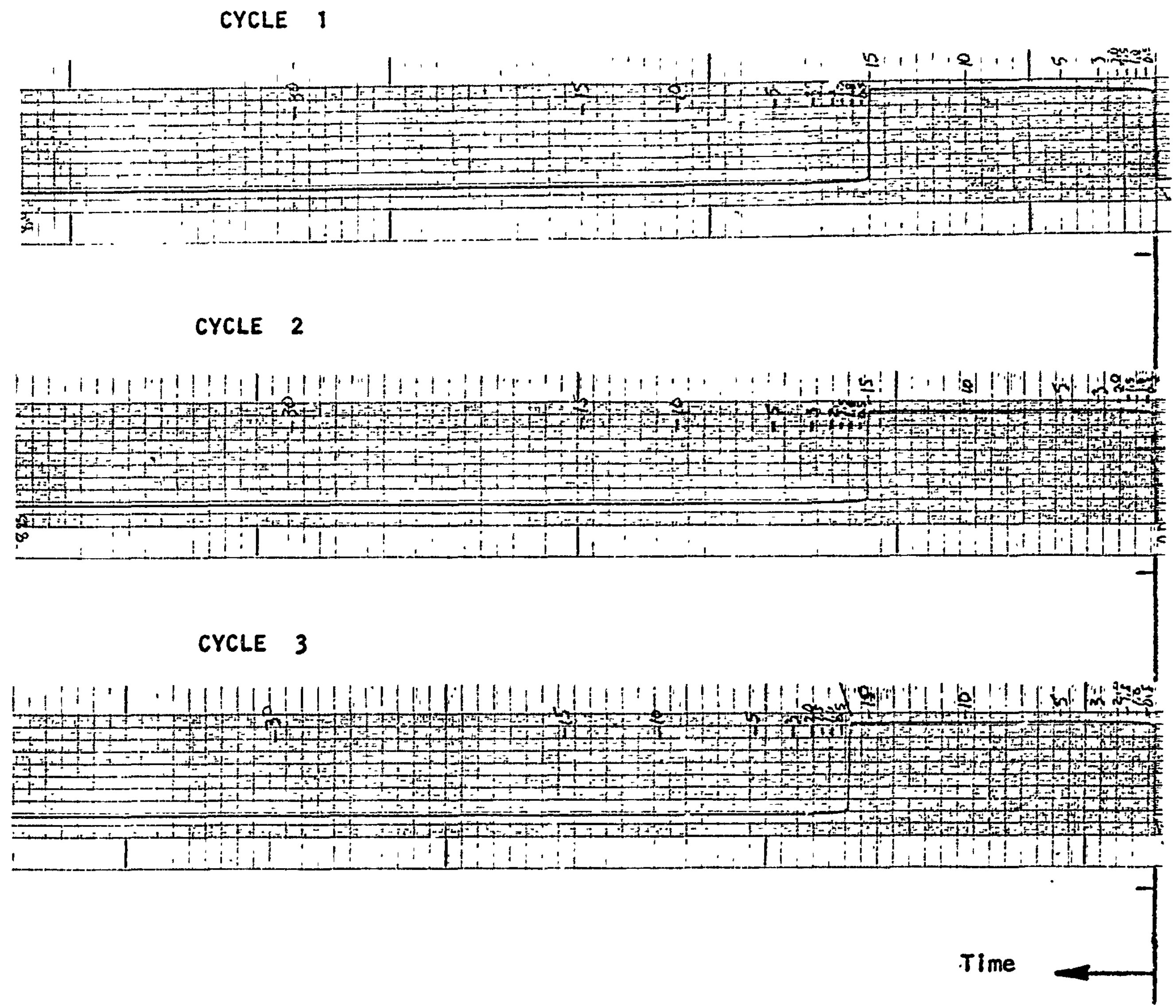


FIGURE 11-8 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 170°F/dry% RH ENVIRONMENT AND 15 % ULTIMATE LOAD LEVEL

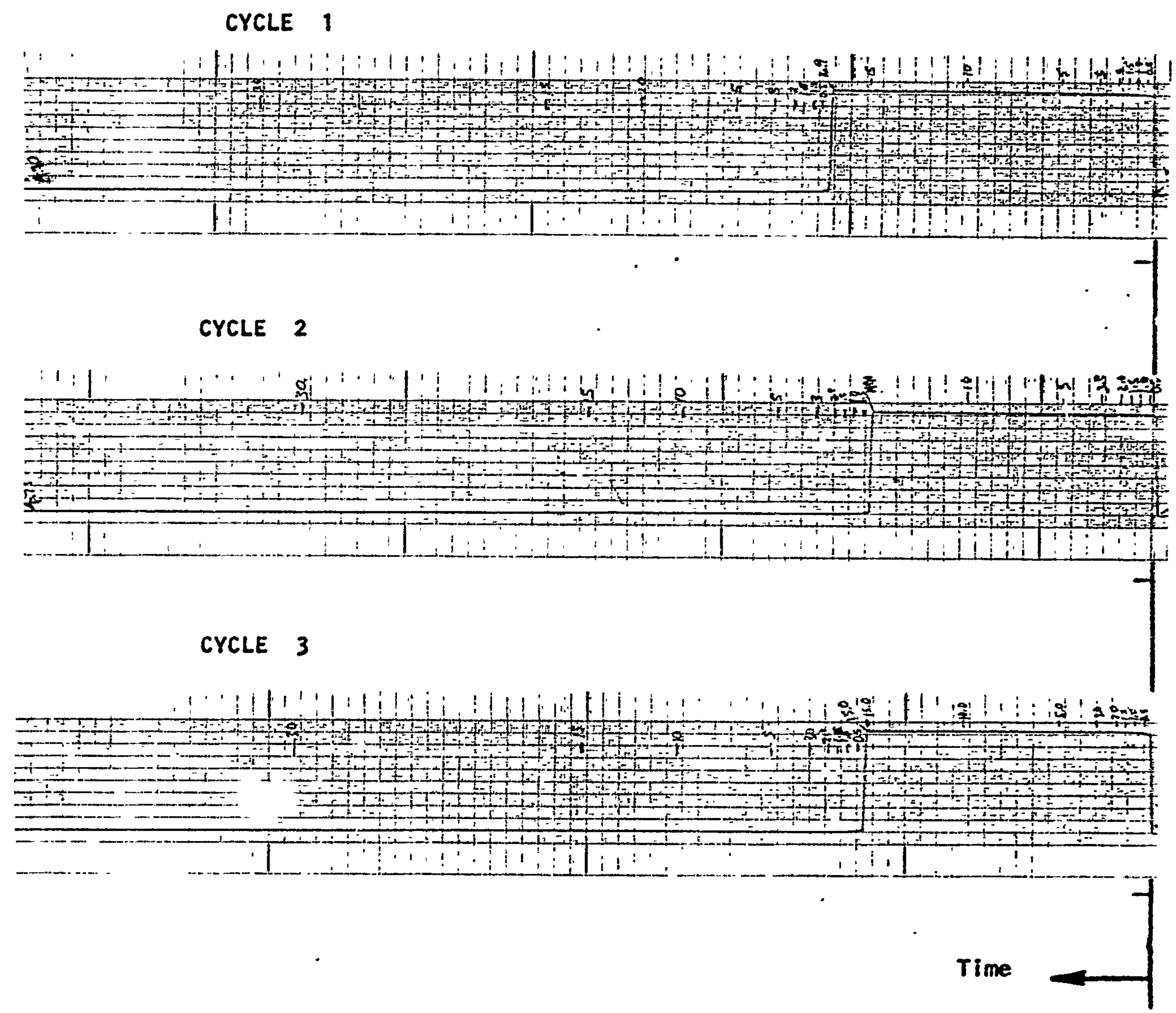


FIGURE 11-9 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 75 °F/dry% RH ENVIRONMENT AND 20% ULTIMATE LOAD LEVEL

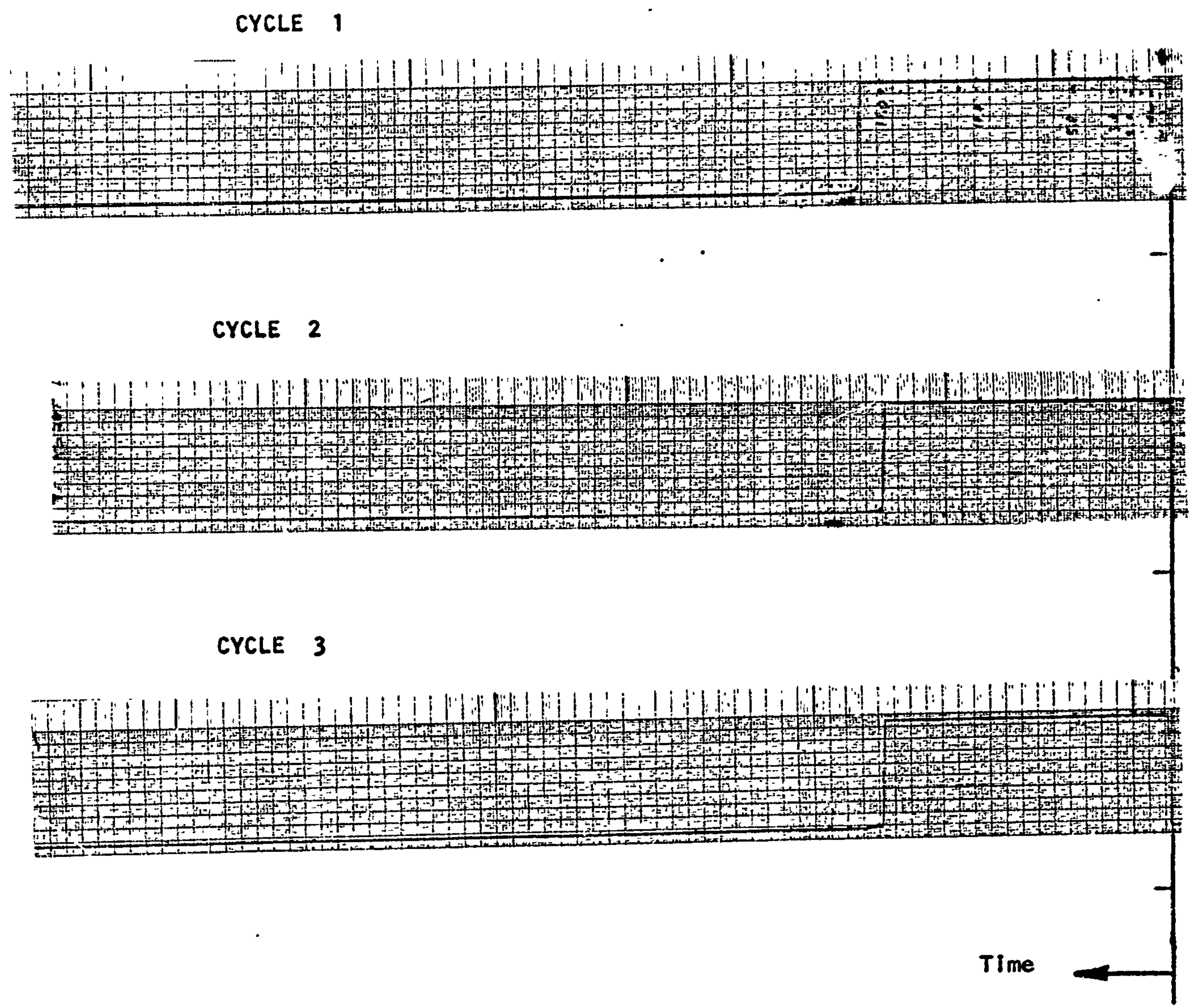


FIGURE 11-10 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 120°F/dry% RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

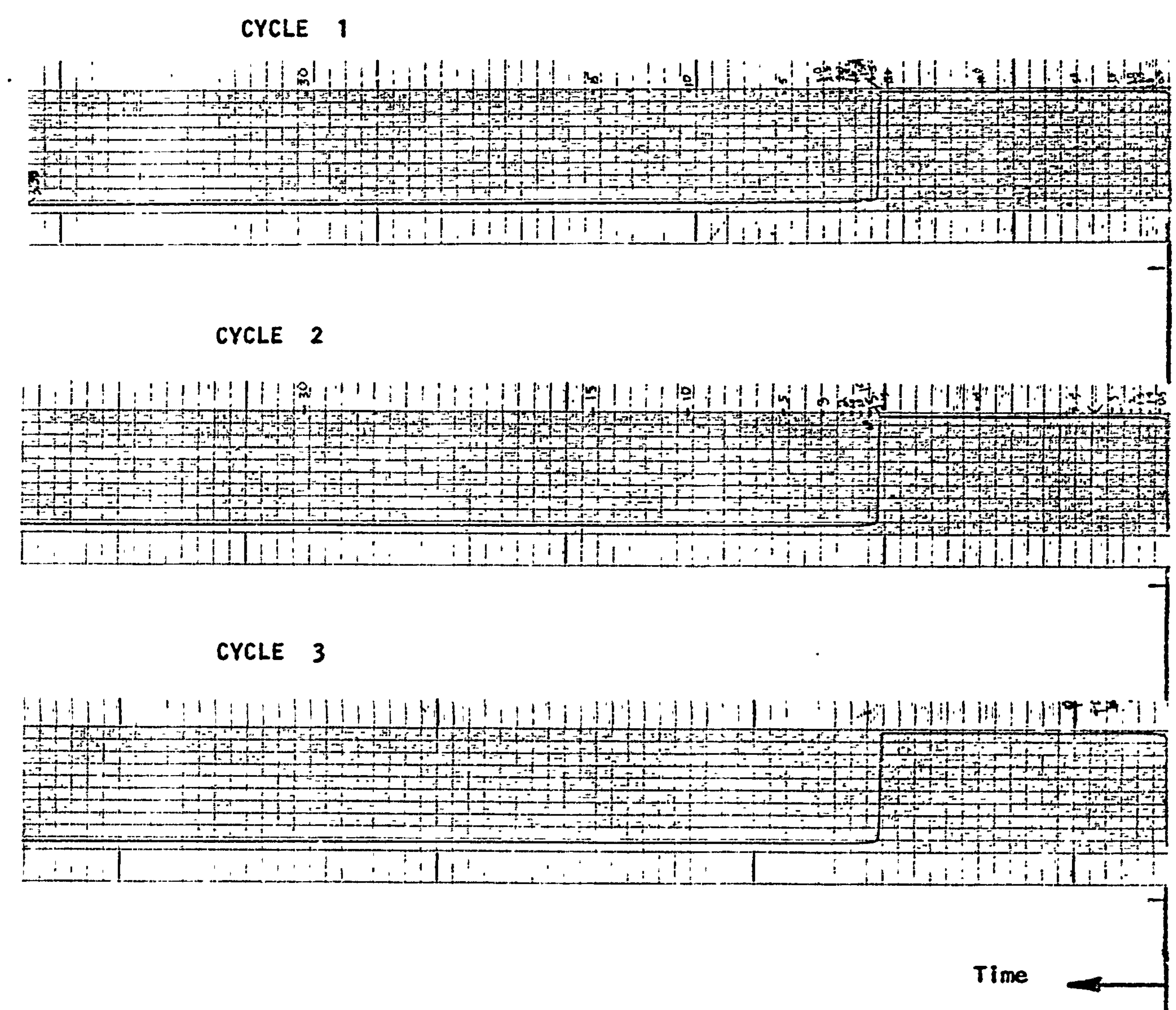


FIGURE 11-11 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT $150^{\circ}F$/dry % RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

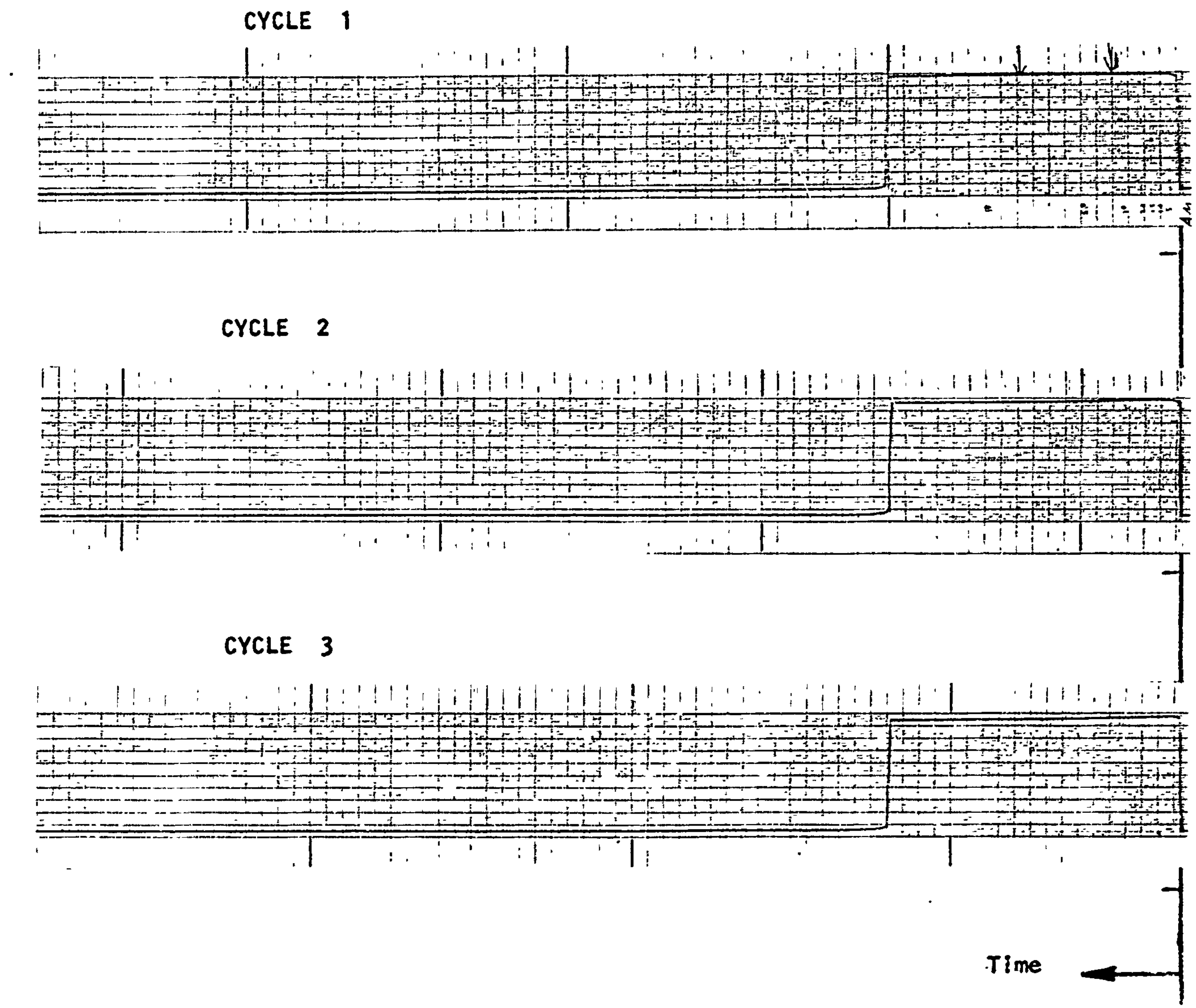


FIGURE 11-12 CREEP-RECOVERY CURVES FOR 0° SPECIMENS AT 170°F/dry% RH ENVIRONMENT AND 20% ULTIMATE LOAD LEVEL

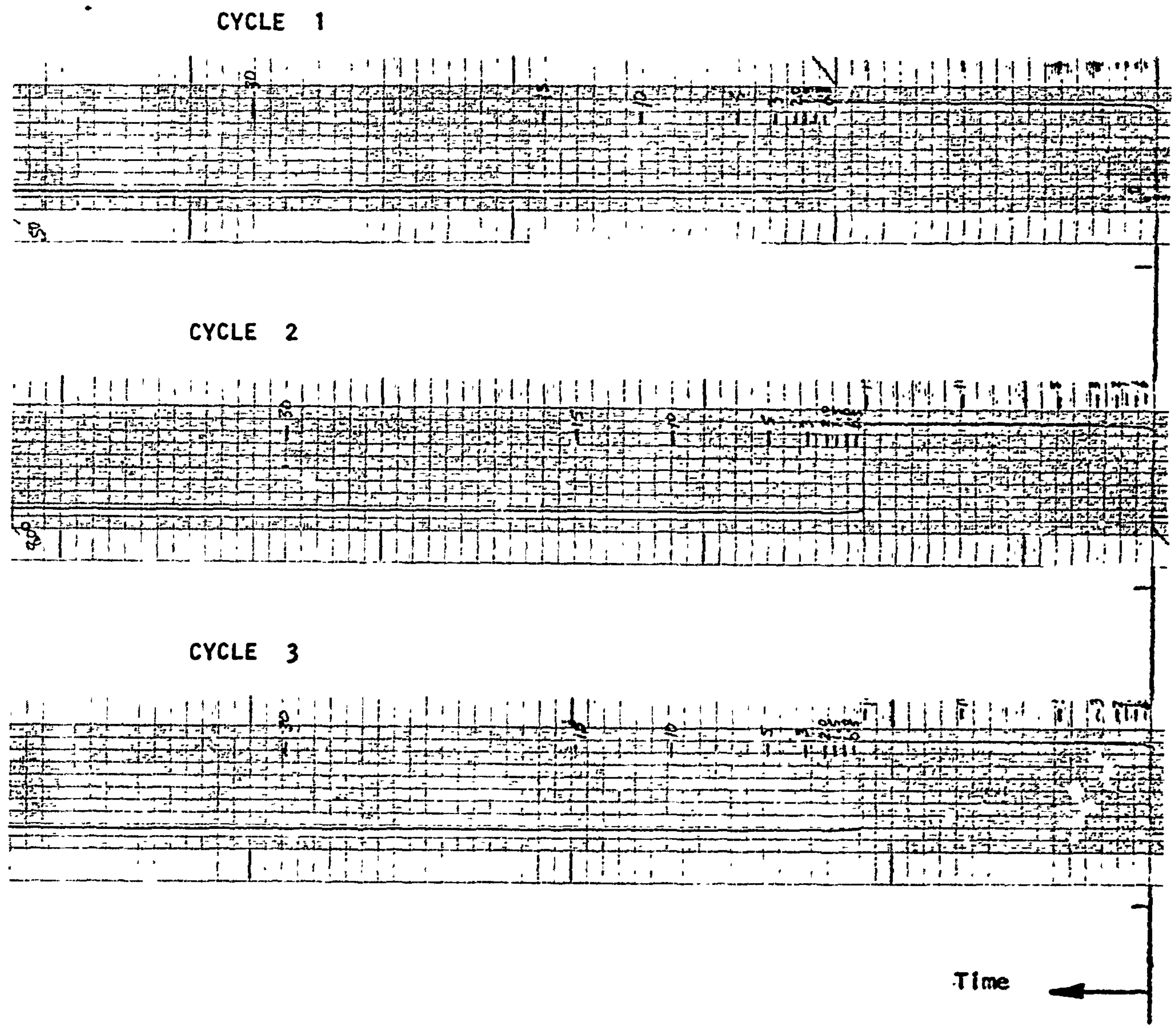


FIGURE 11-13 CREEP-RECOVERY C.RVES FOR $\pm 45^{\circ}$ SPECIMENS AT 75 °F/dry% RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

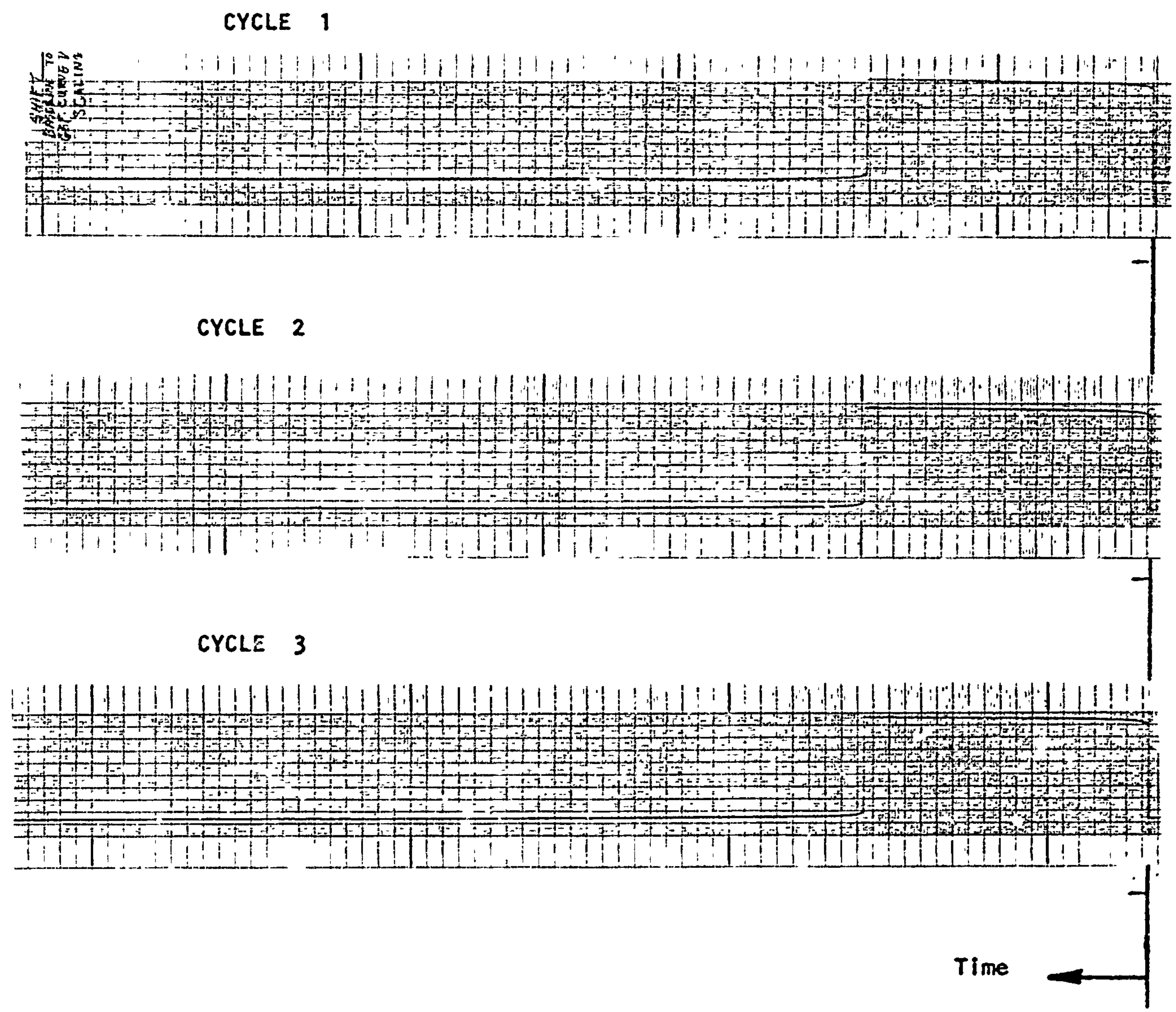


FIGURE 11-14 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 120 °F/ dry% RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

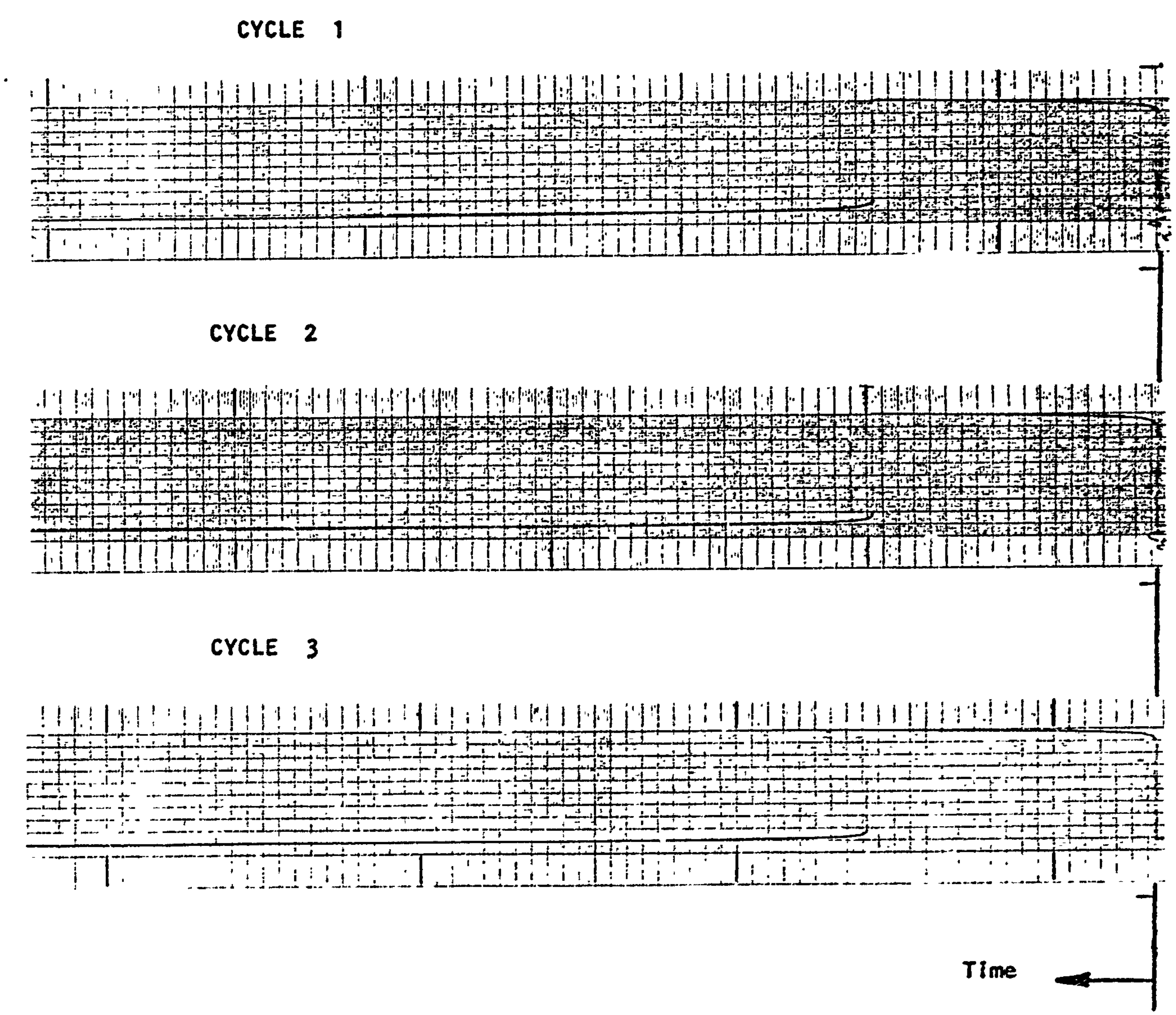


FIGURE 11-15 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 150°F/dry% RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

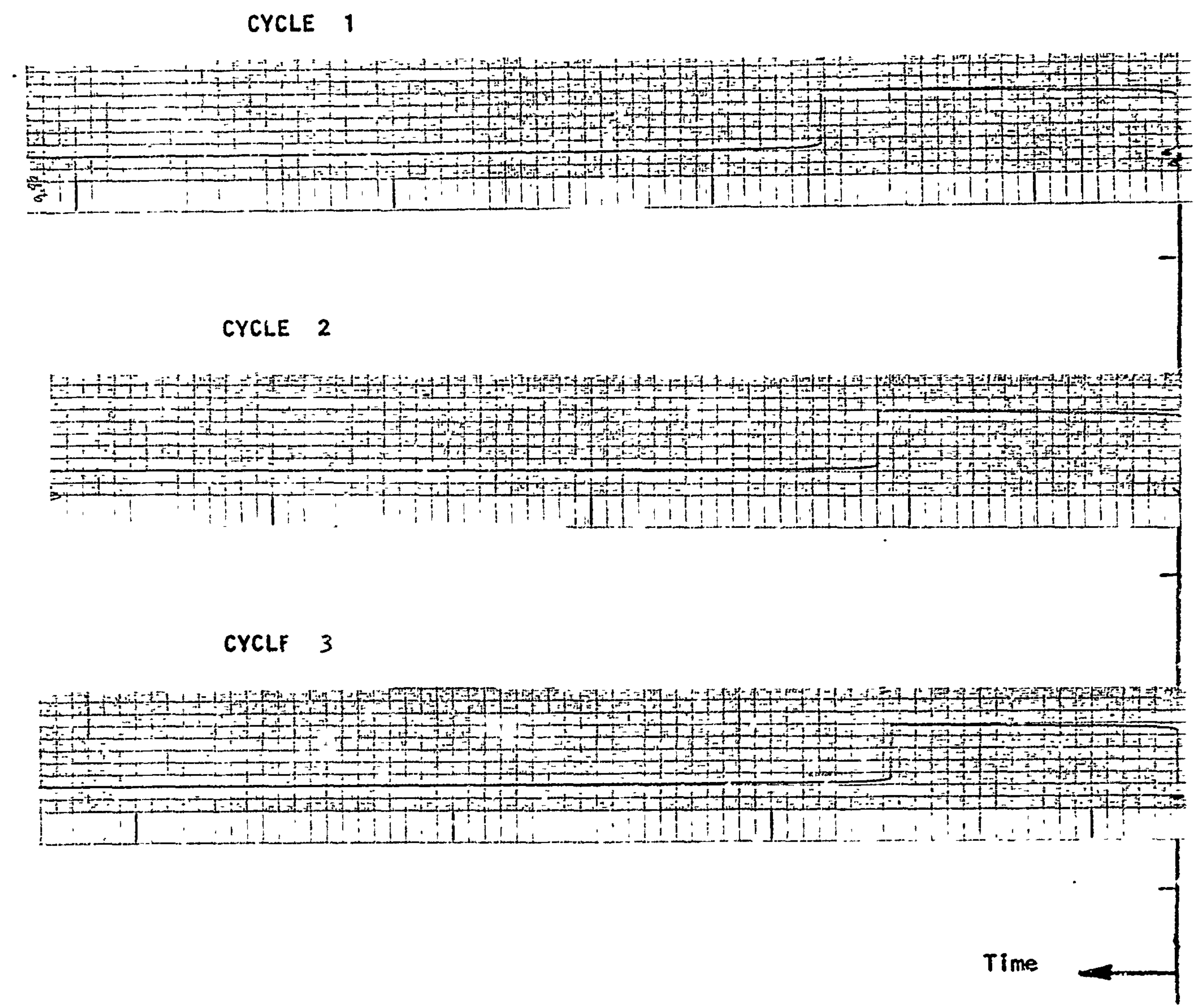


FIGURE 11-16 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 170 °F/ dry% RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

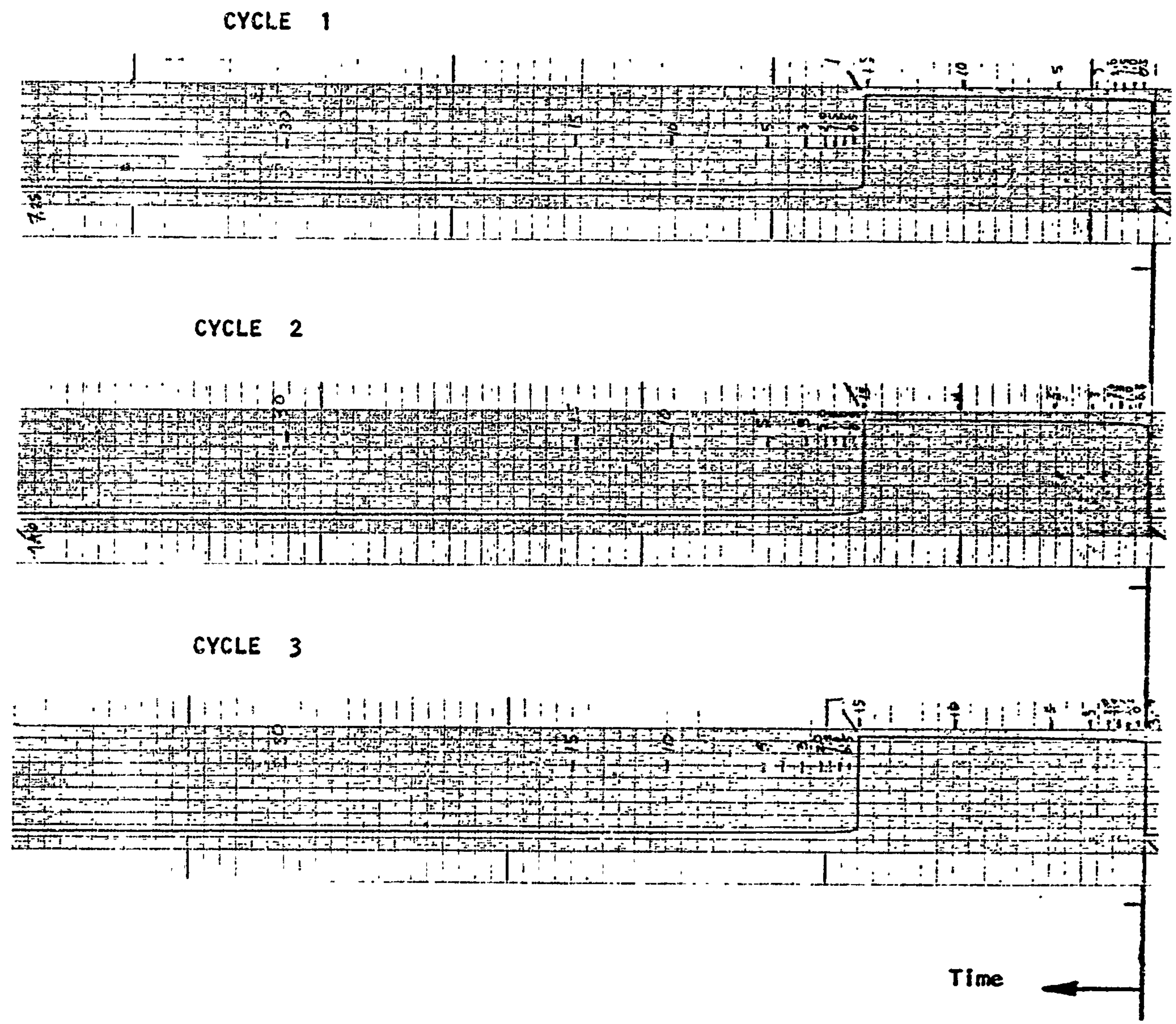


FIGURE 11-17 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 75 °F/dry % RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

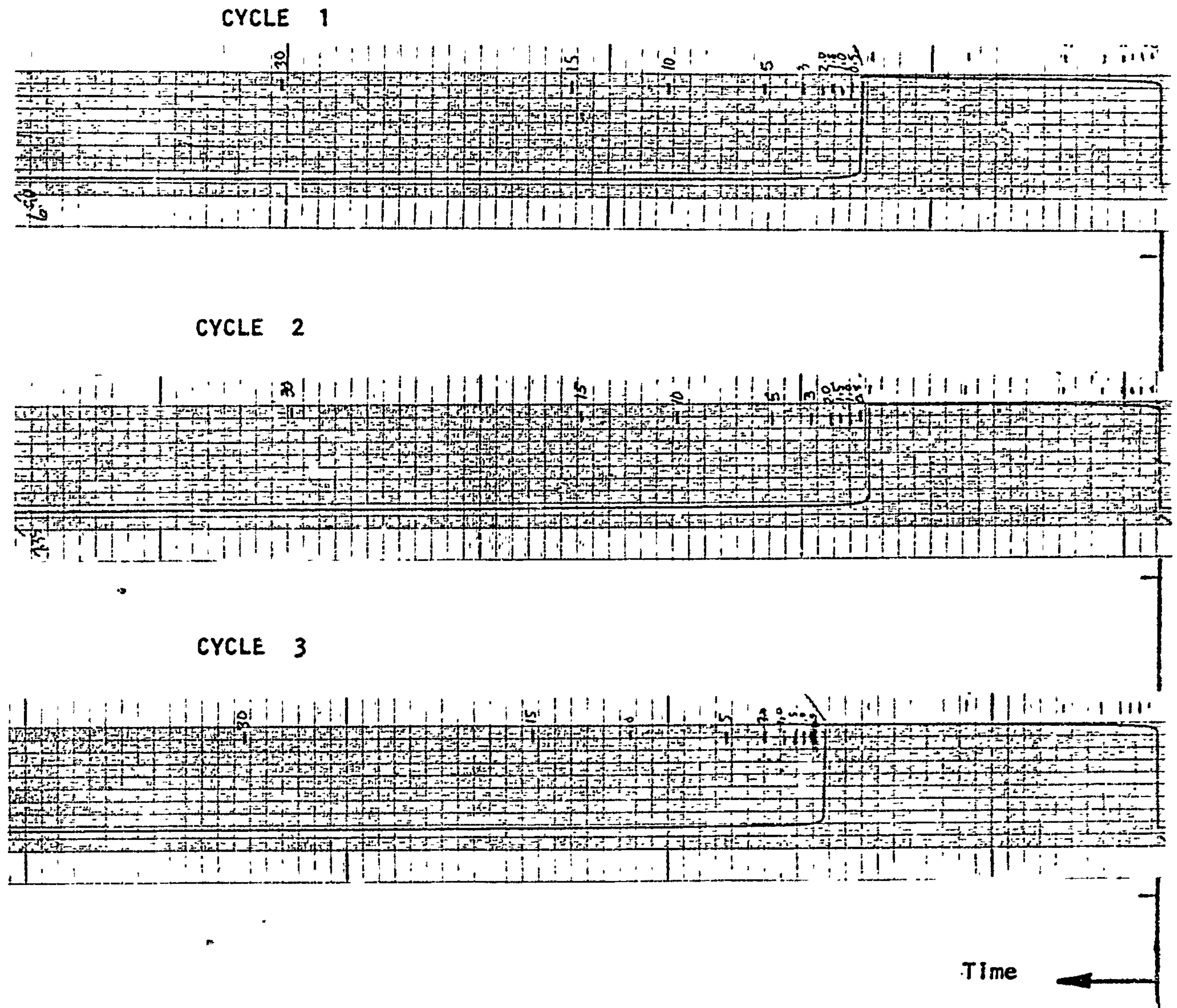


FIGURE 11-18 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120^{\circ}F$/dry % RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

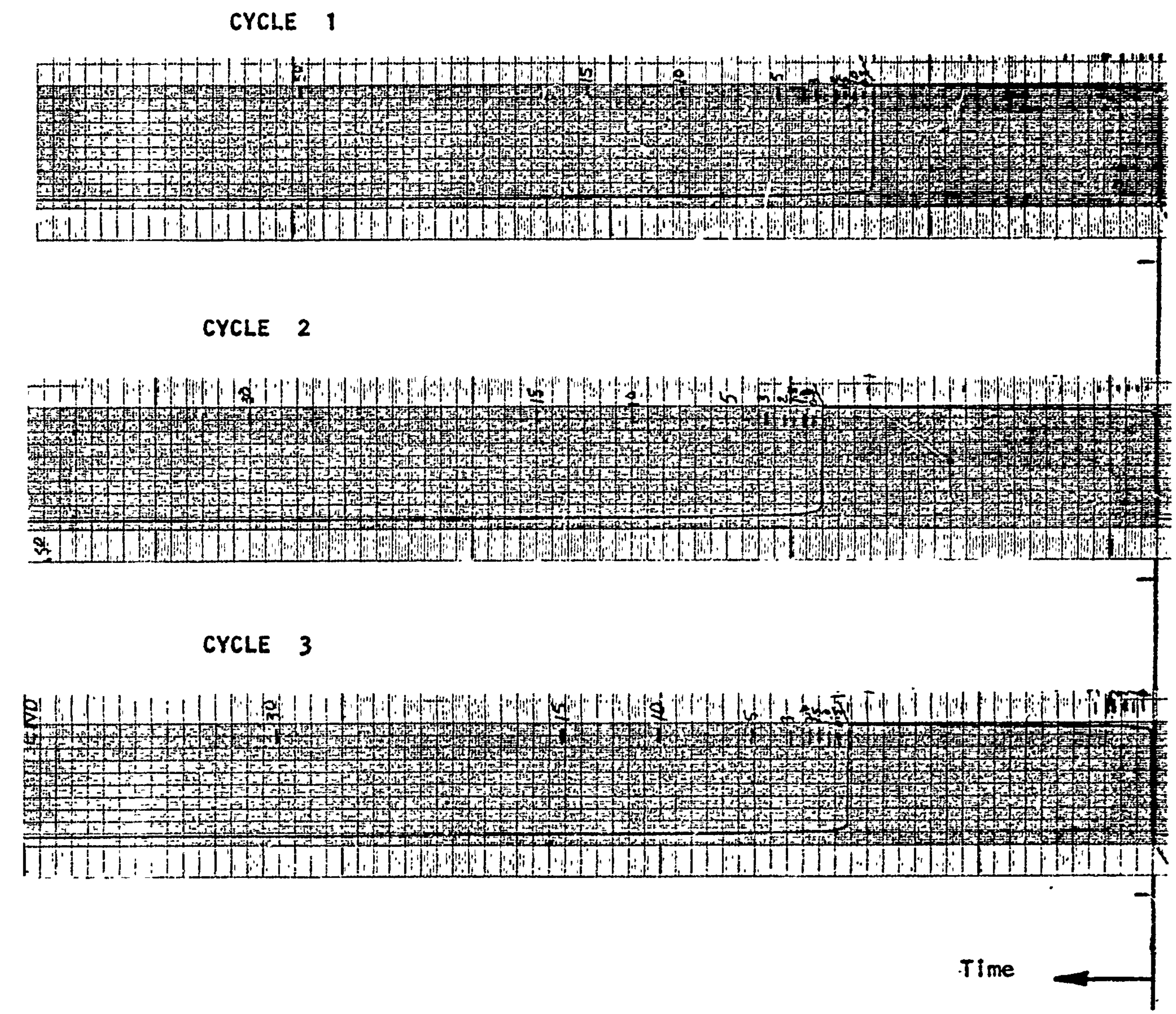


FIGURE 11-19 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 150°F/dry% RH ENVIRONMENT AND 40% ULTIMATE LOAD LEVEL

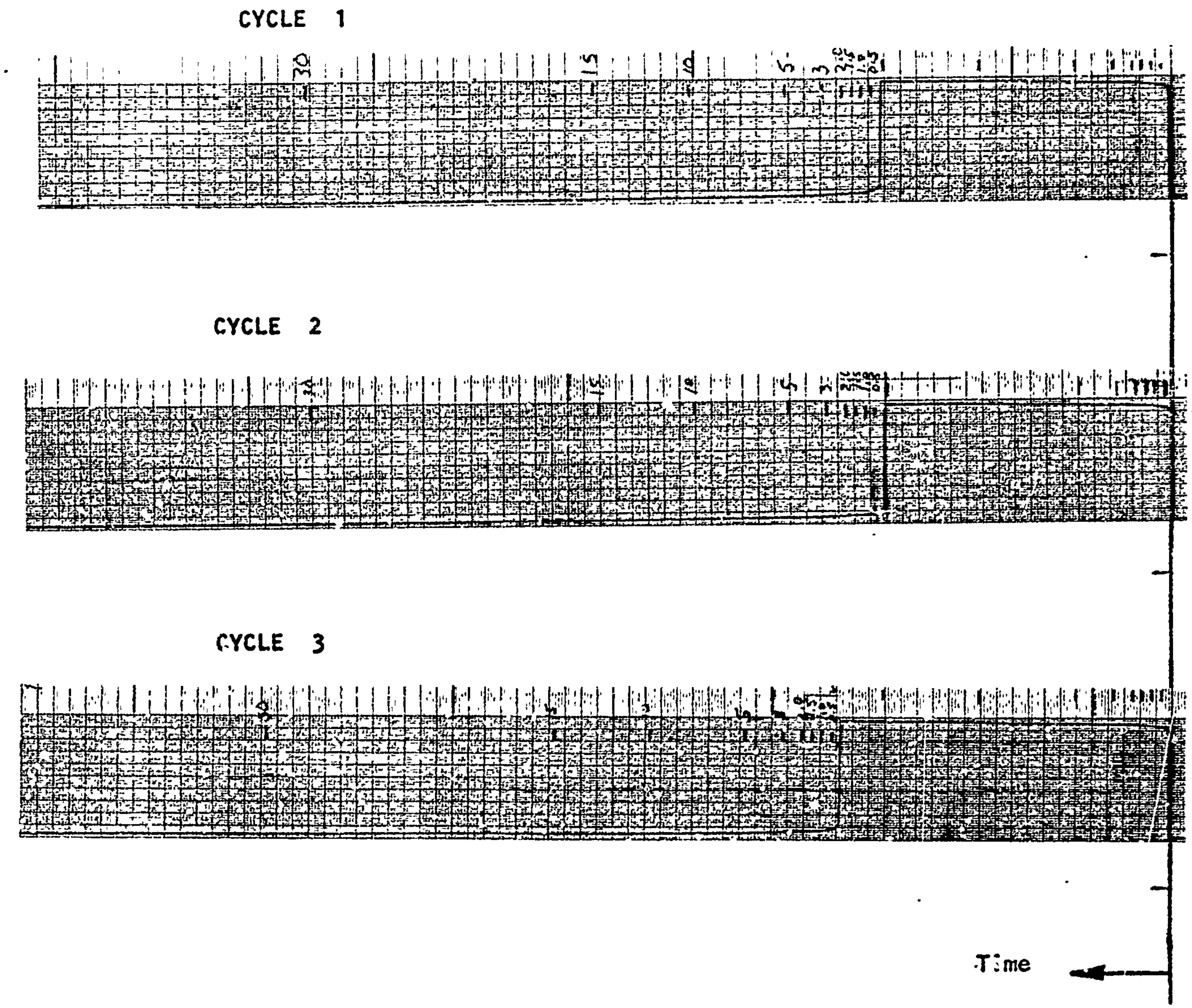


FIGURE 11-20 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 170°F/dry% RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

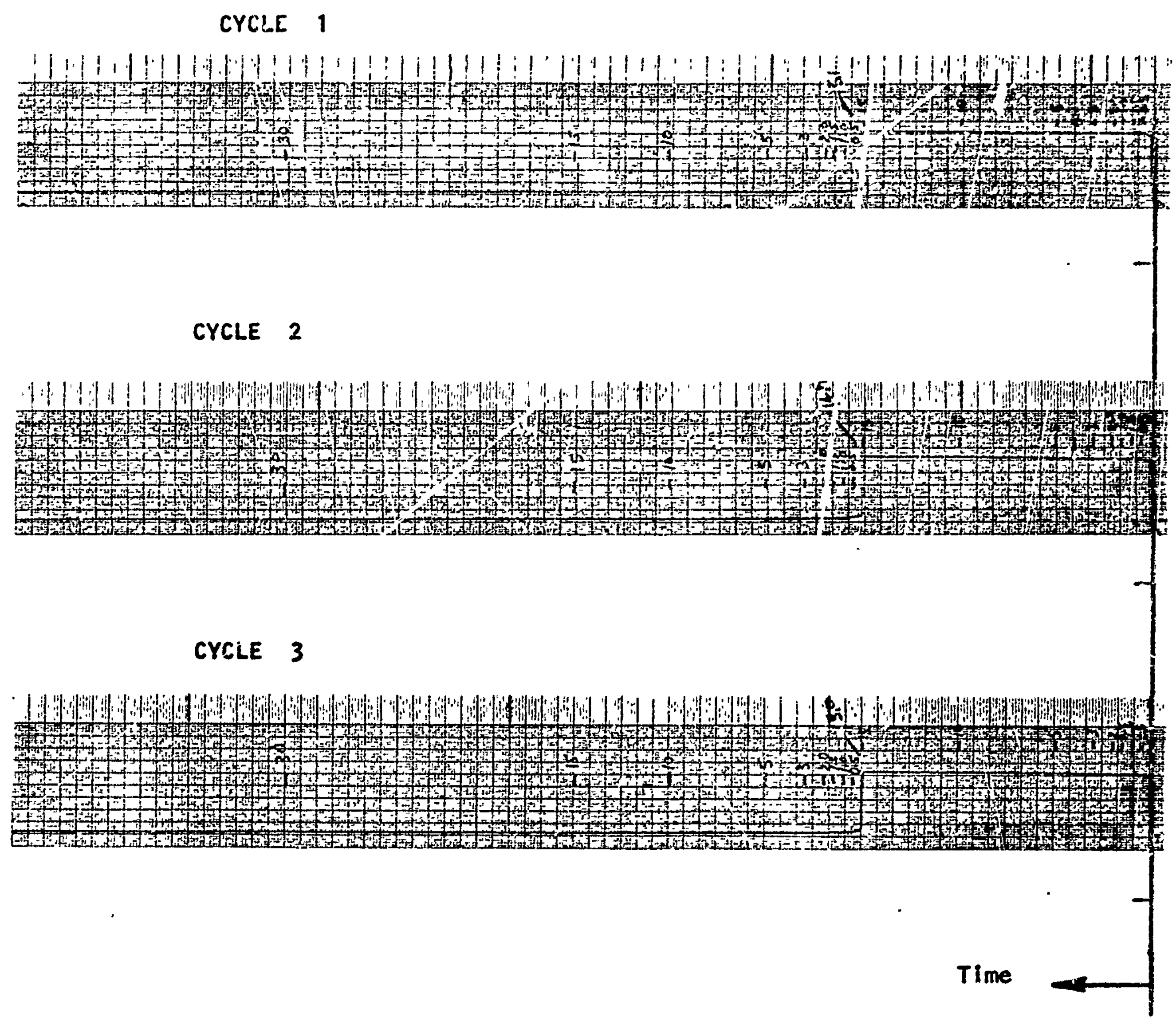


FIGURE 11-21 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 75 °F/dry % RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

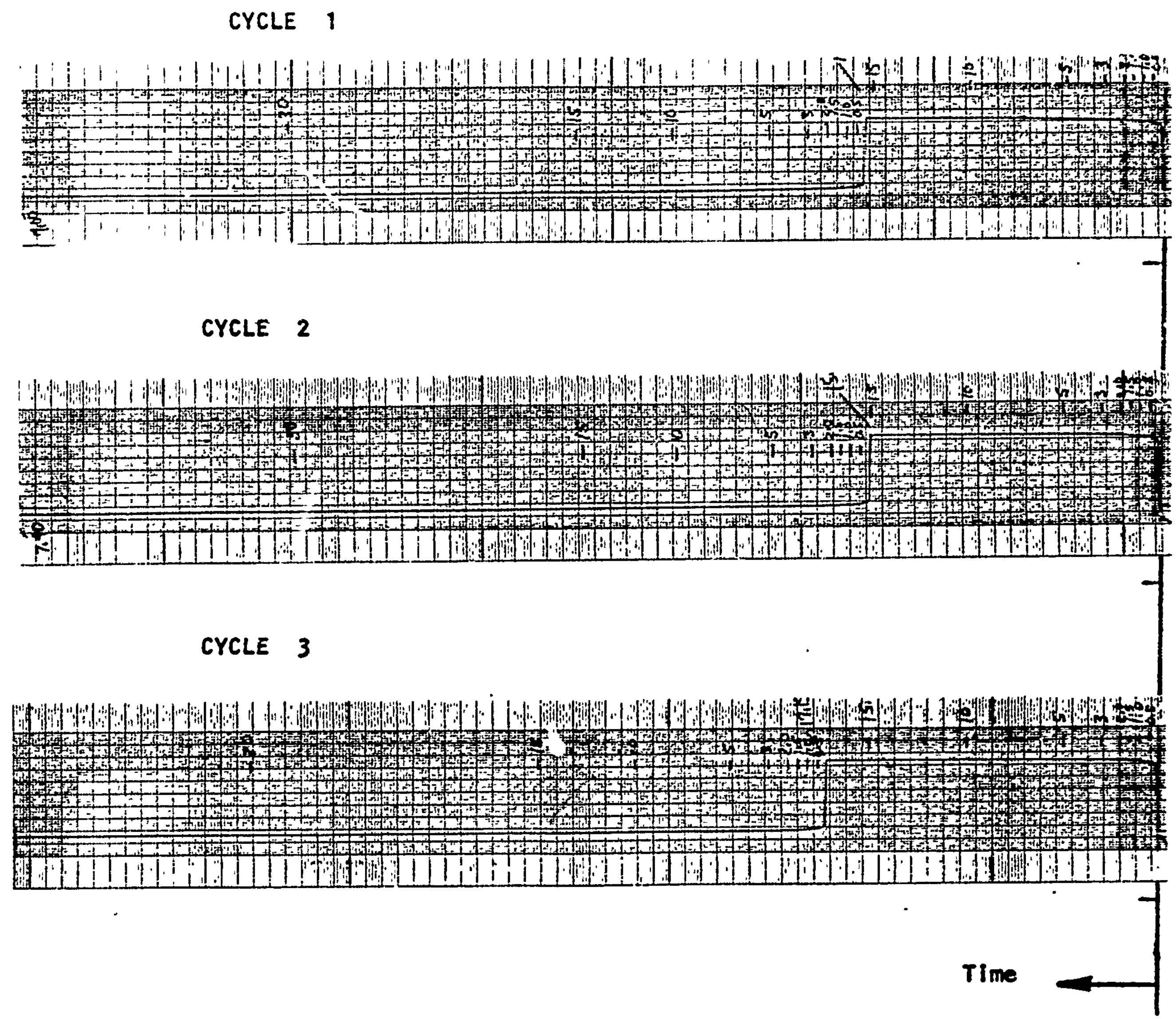


FIGURE 11-22 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 120°F/dry% RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

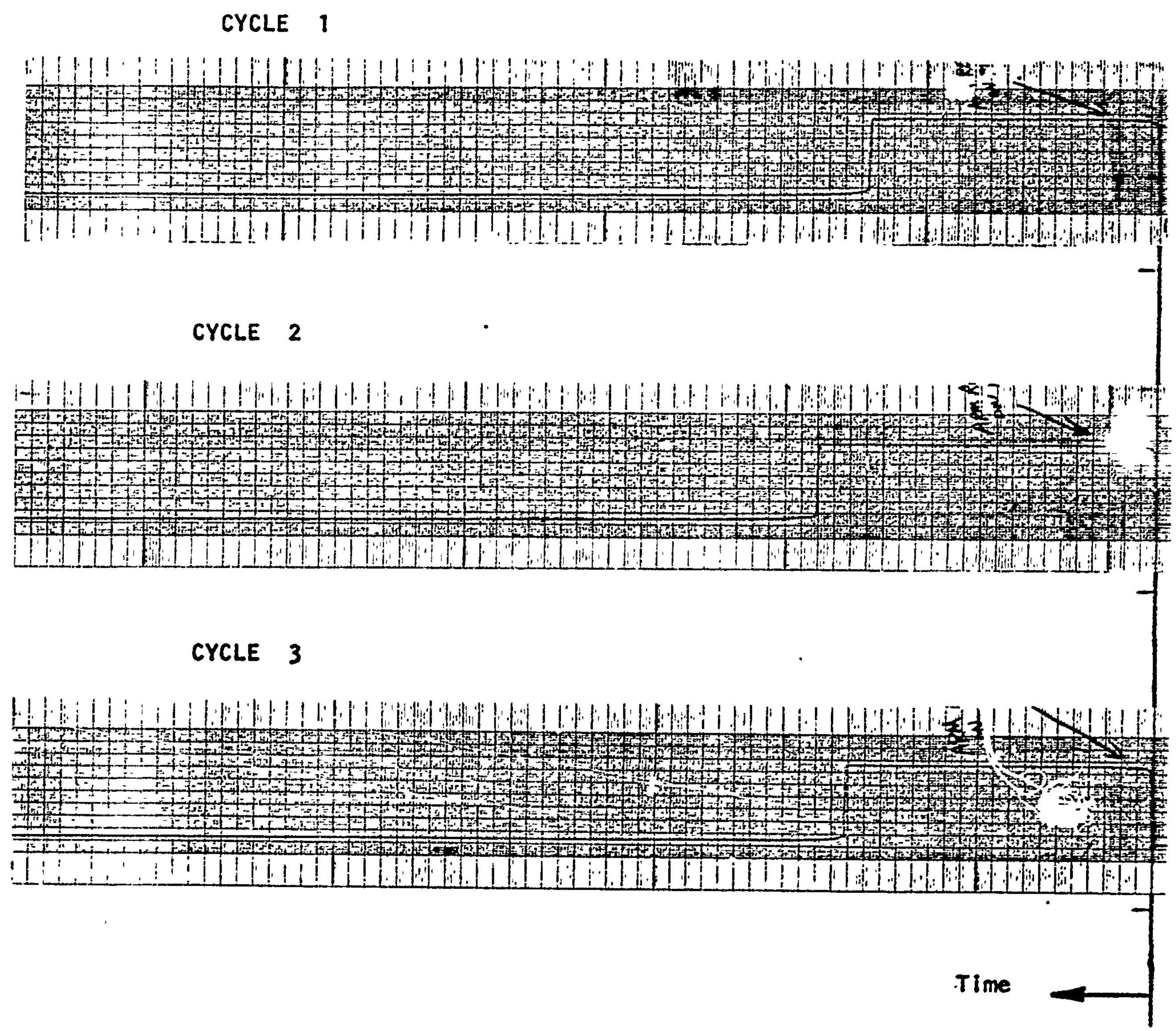


FIGURE 11-23 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 150°F/dry % RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

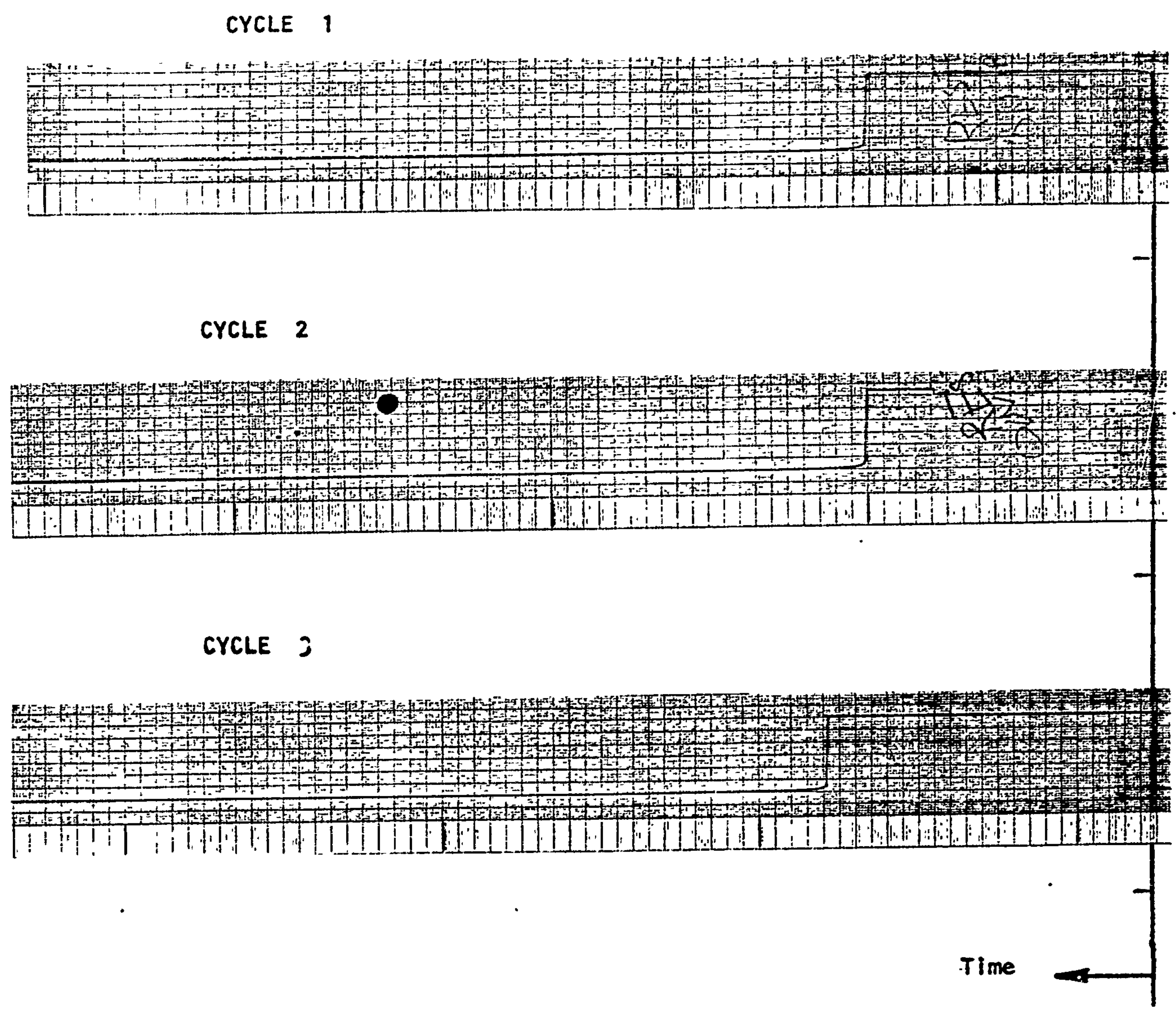


FIGURE 11-24 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 170 °F/dry% RH ENVIRONMENT AND 60% ULTIMATE LOAD LEVEL

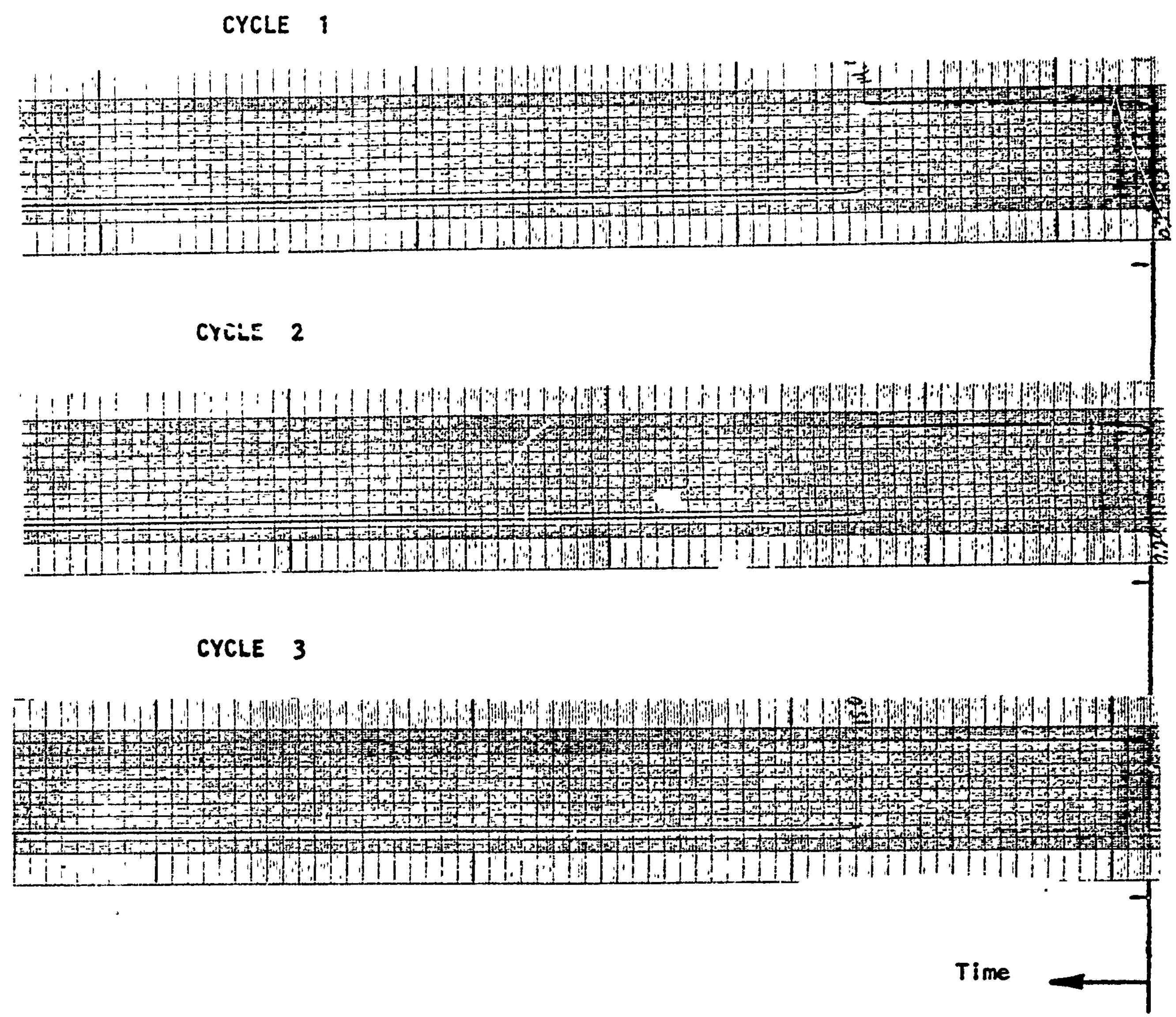


FIGURE 11-25 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $75^{\circ}F/50\%$ RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

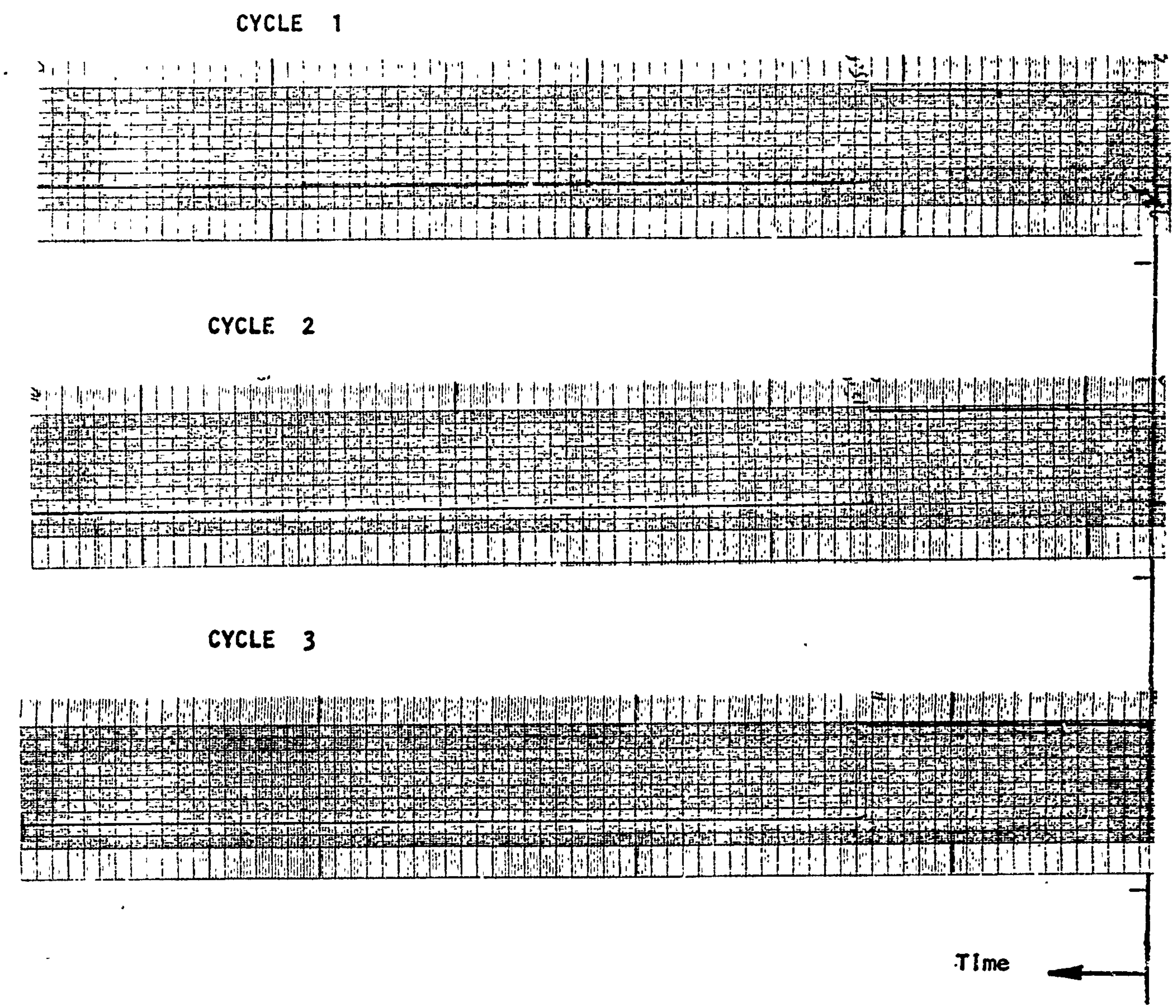


FIGURE 11-26 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120^{\circ}F/50\%$ RH ENVIRONMENT AND 20% ULTIMATE LOAD LEVEL

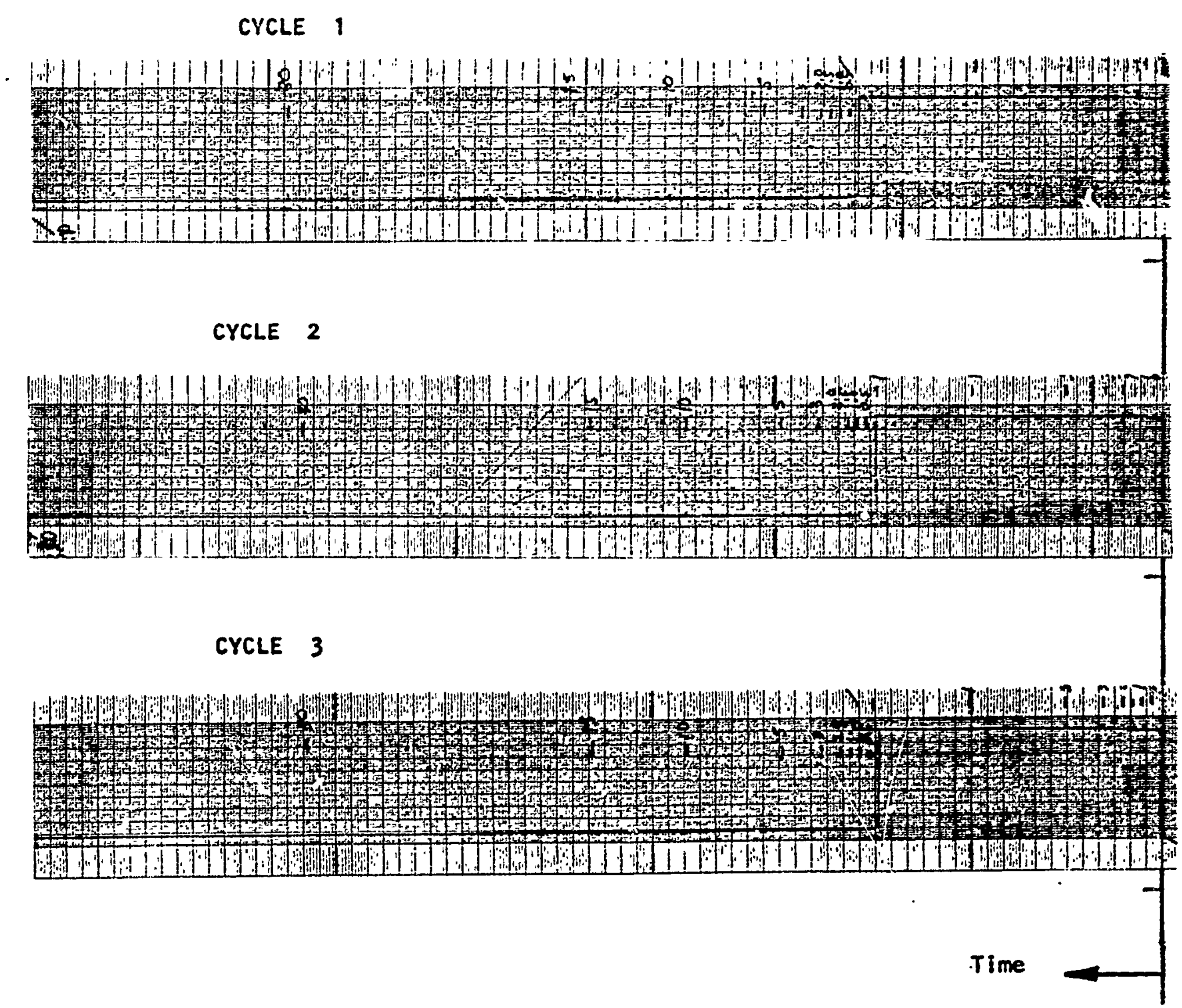


FIGURE 11-27 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $150^{\circ}F/50\%$ RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

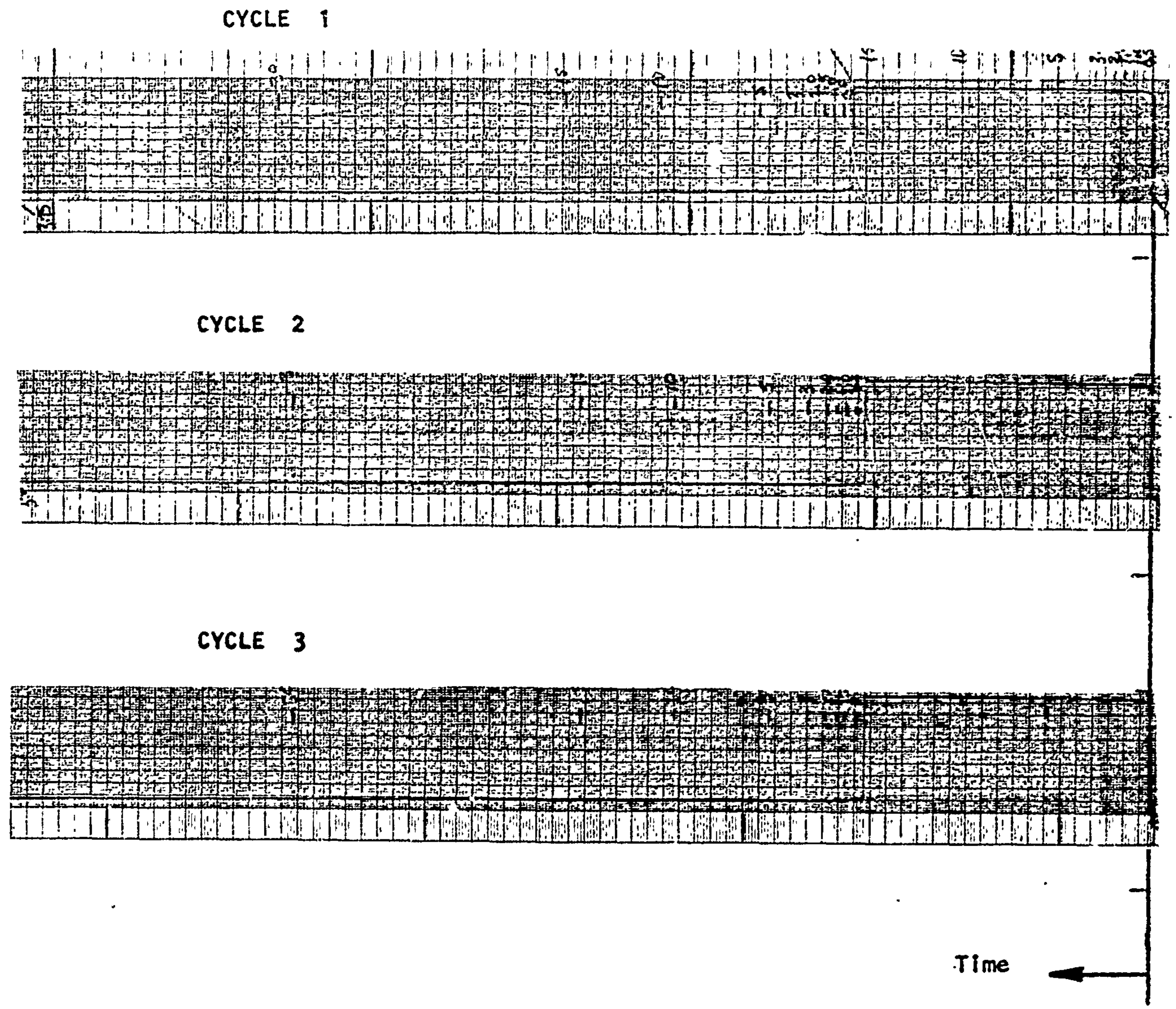


FIGURE 11-28 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $170^{\circ}F/50\%$ RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

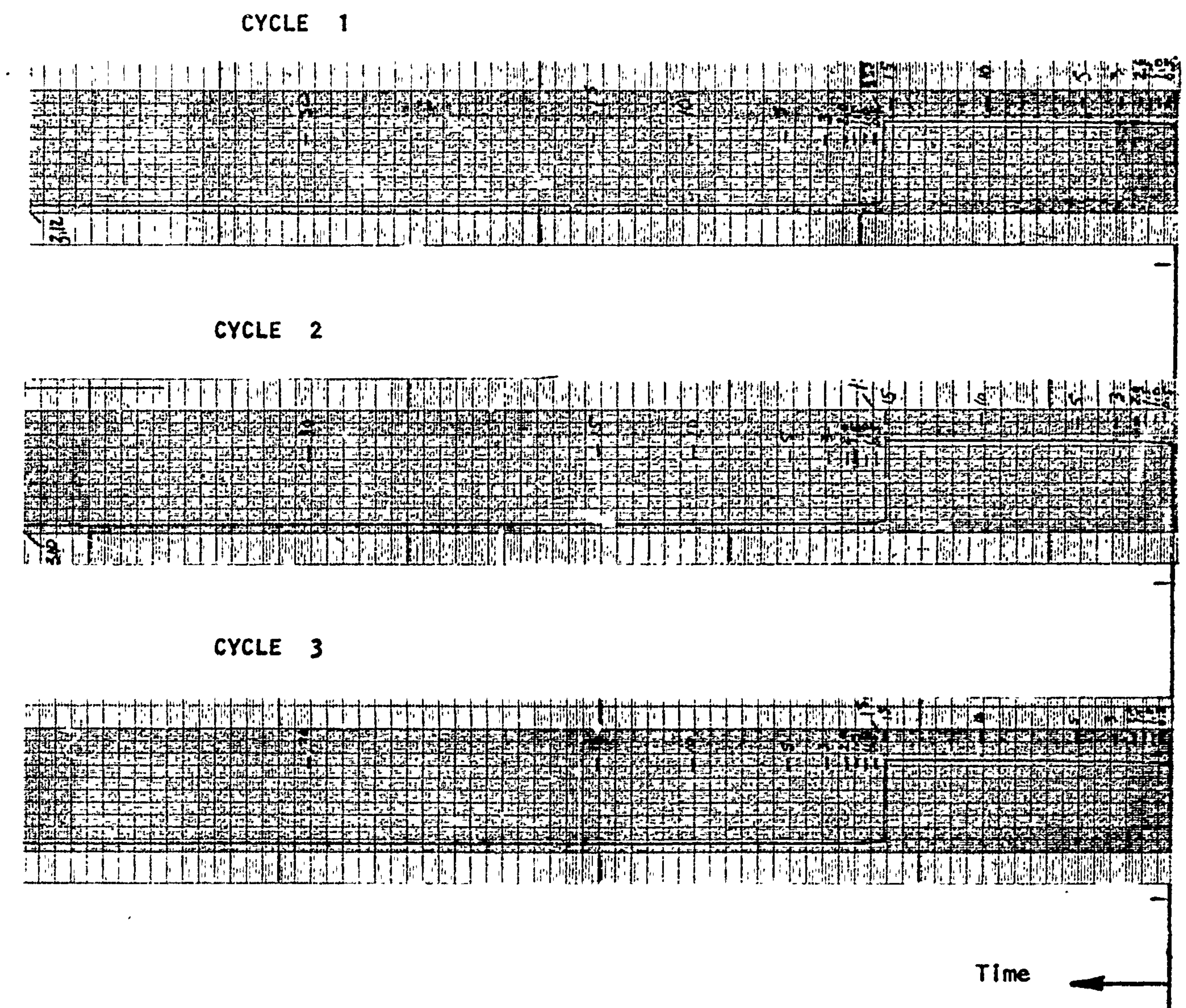


FIGURE 11-29 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $75\,^{\circ}F/50\,\%$ RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

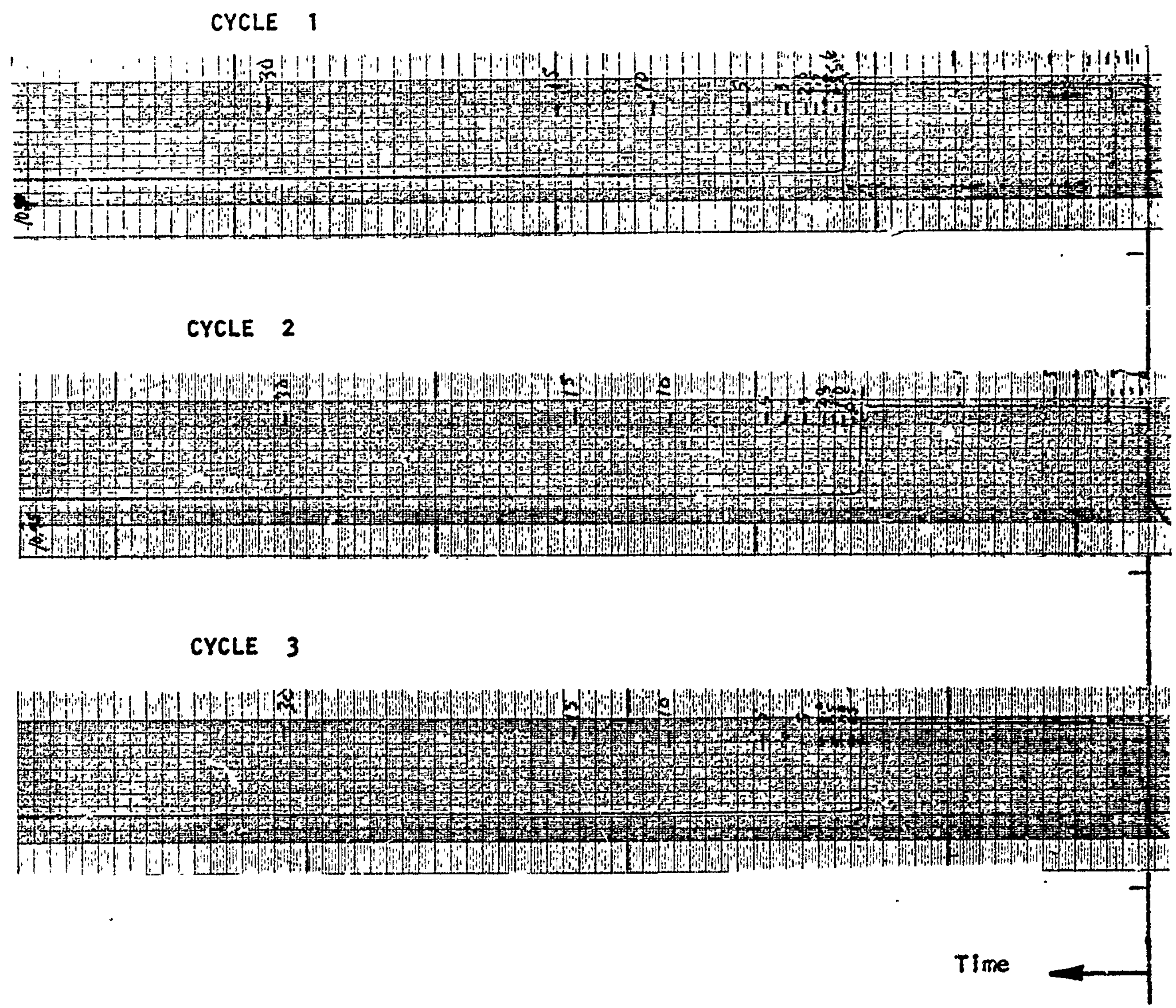


FIGURE 11-30 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120^{\circ}F$/ 50 % RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

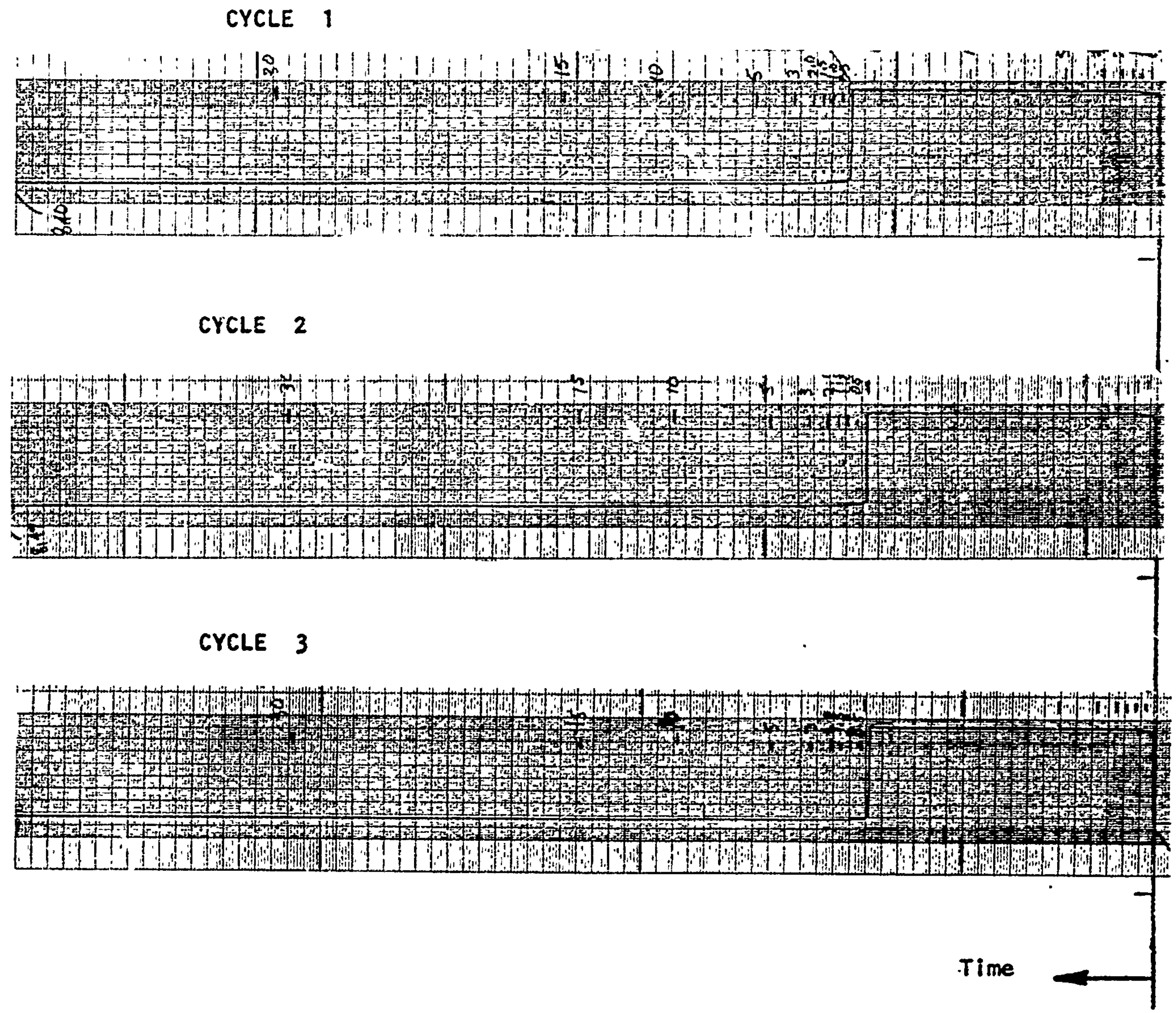


FIGURE 11-31 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $150^{\circ}F/50\%$ RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

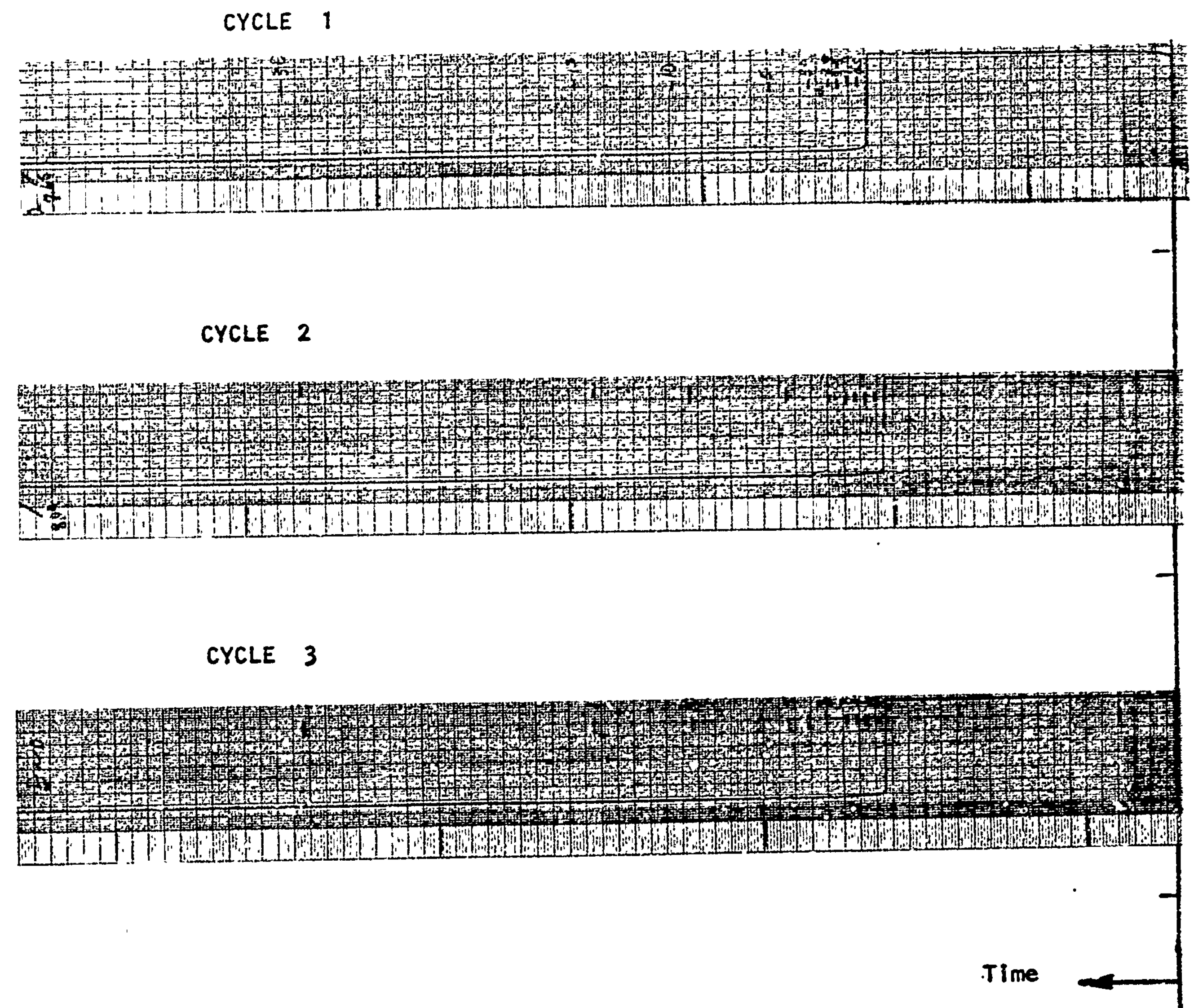


FIGURE 11-32 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $170^{\circ}F/50\%$ RH ENVIRONMENT AND 40% ULTIMATE LOAD LEVEL

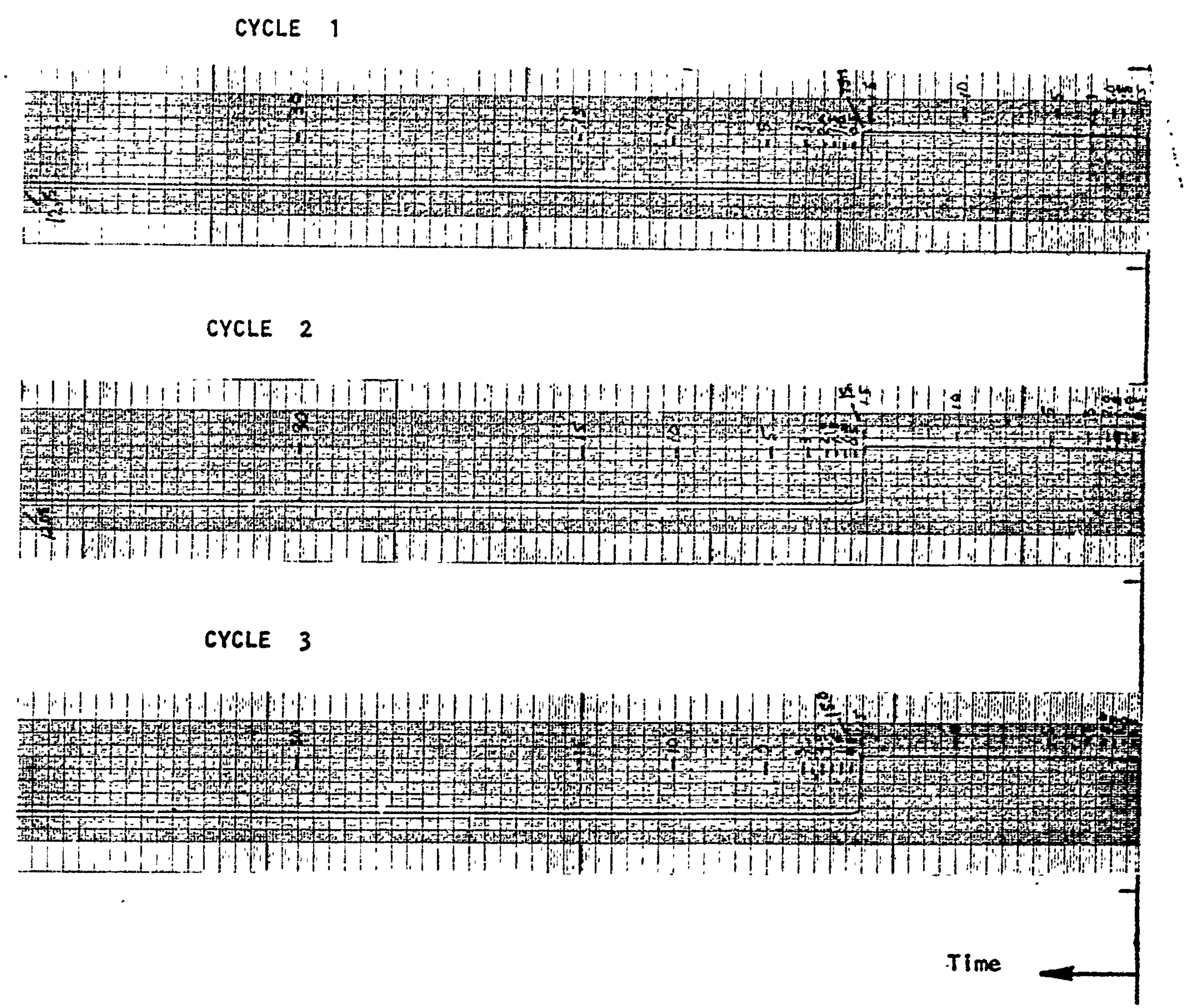


FIGURE II-33 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $75^{\circ}F/50\%$ RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

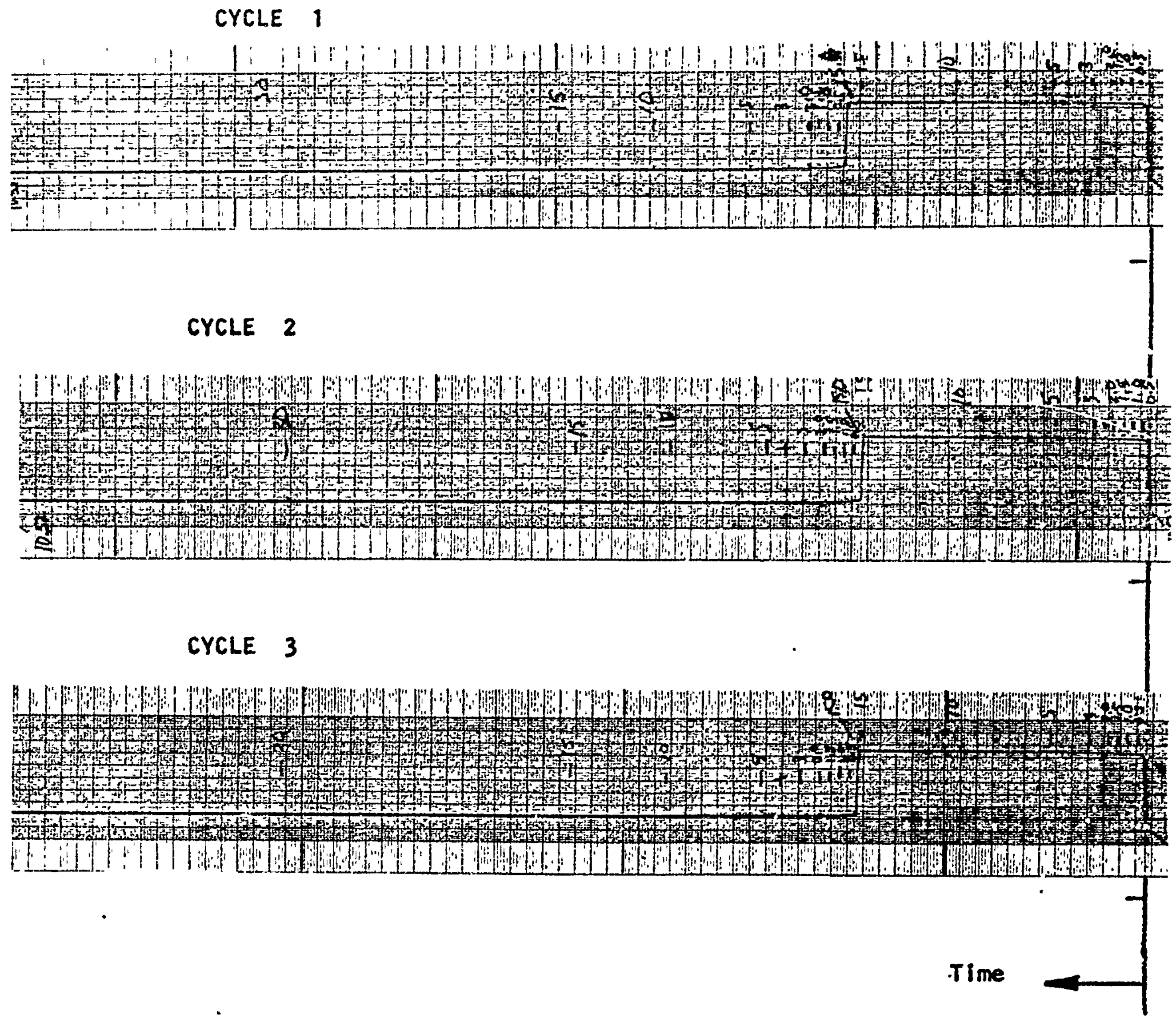


FIGURE 11-34 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 120°F/ 50% RH ENVIRONMENT AND 60% ULTIMATE LOAD LEVEL

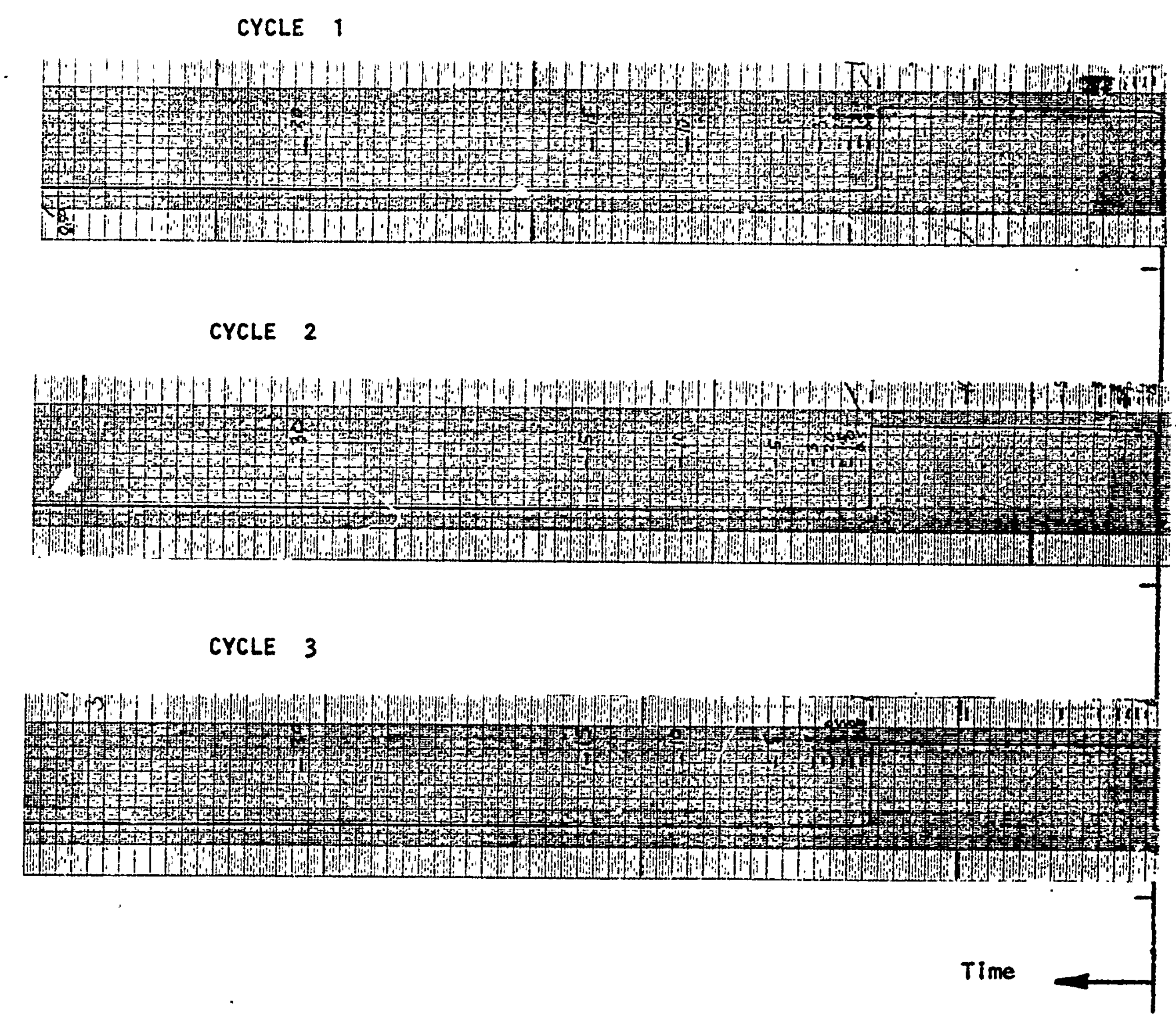


FIGURE 11-35 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $75\ ^{\circ}F$/ 60% RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

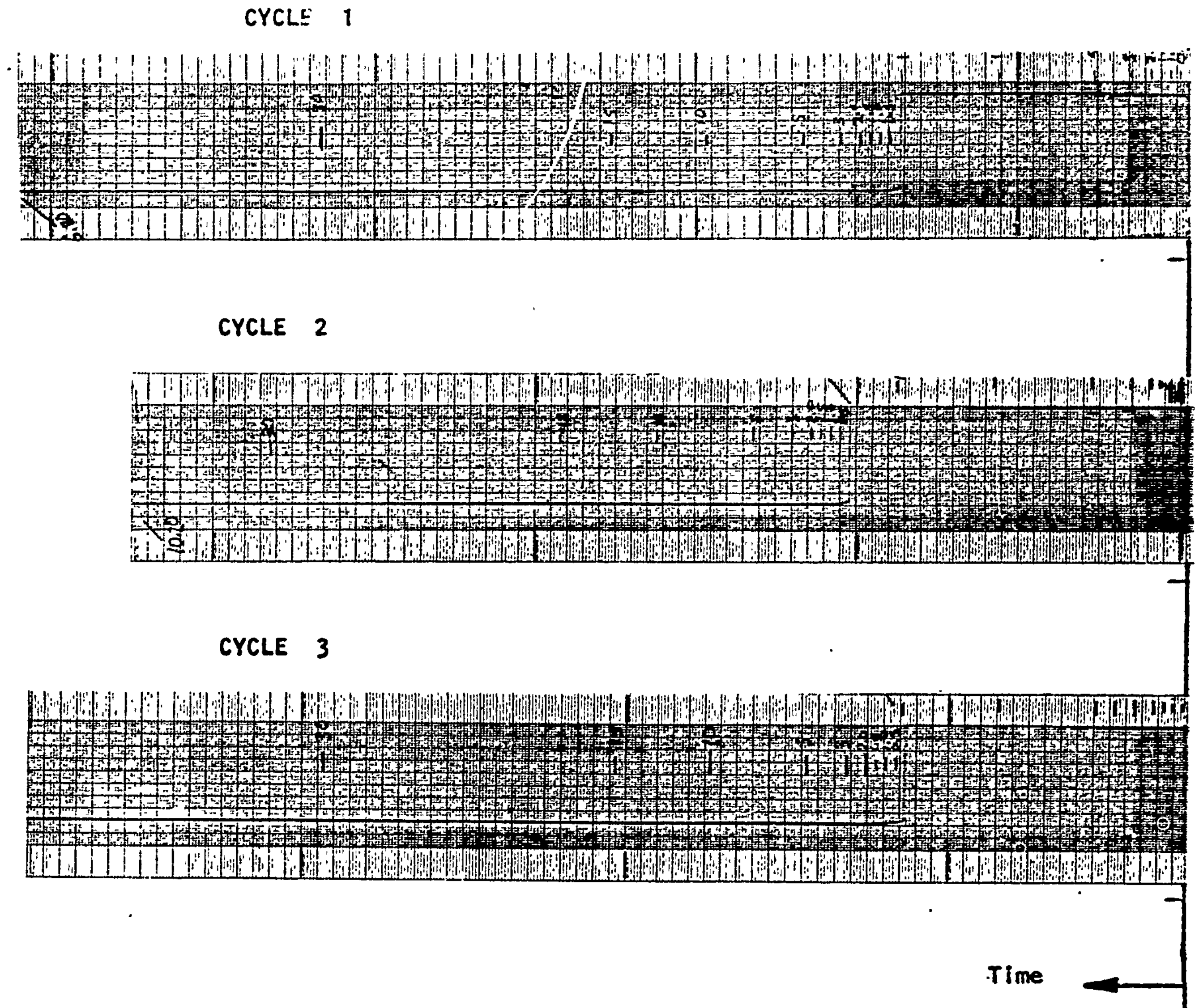


FIGURE 11-36 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120^{\circ}F/60$ % RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

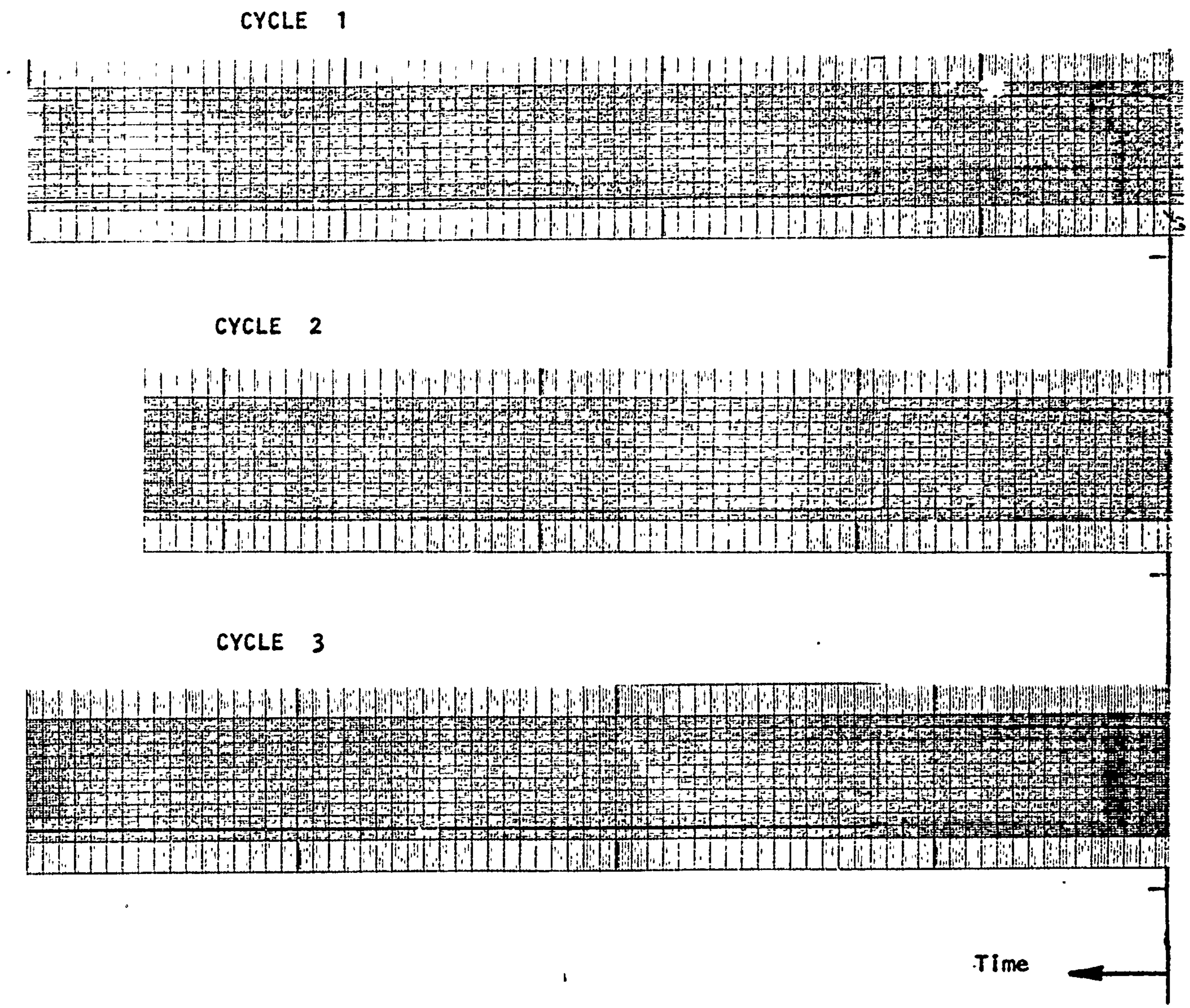


FIGURE 11-37 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 150 $^{\circ}$F/60 % RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

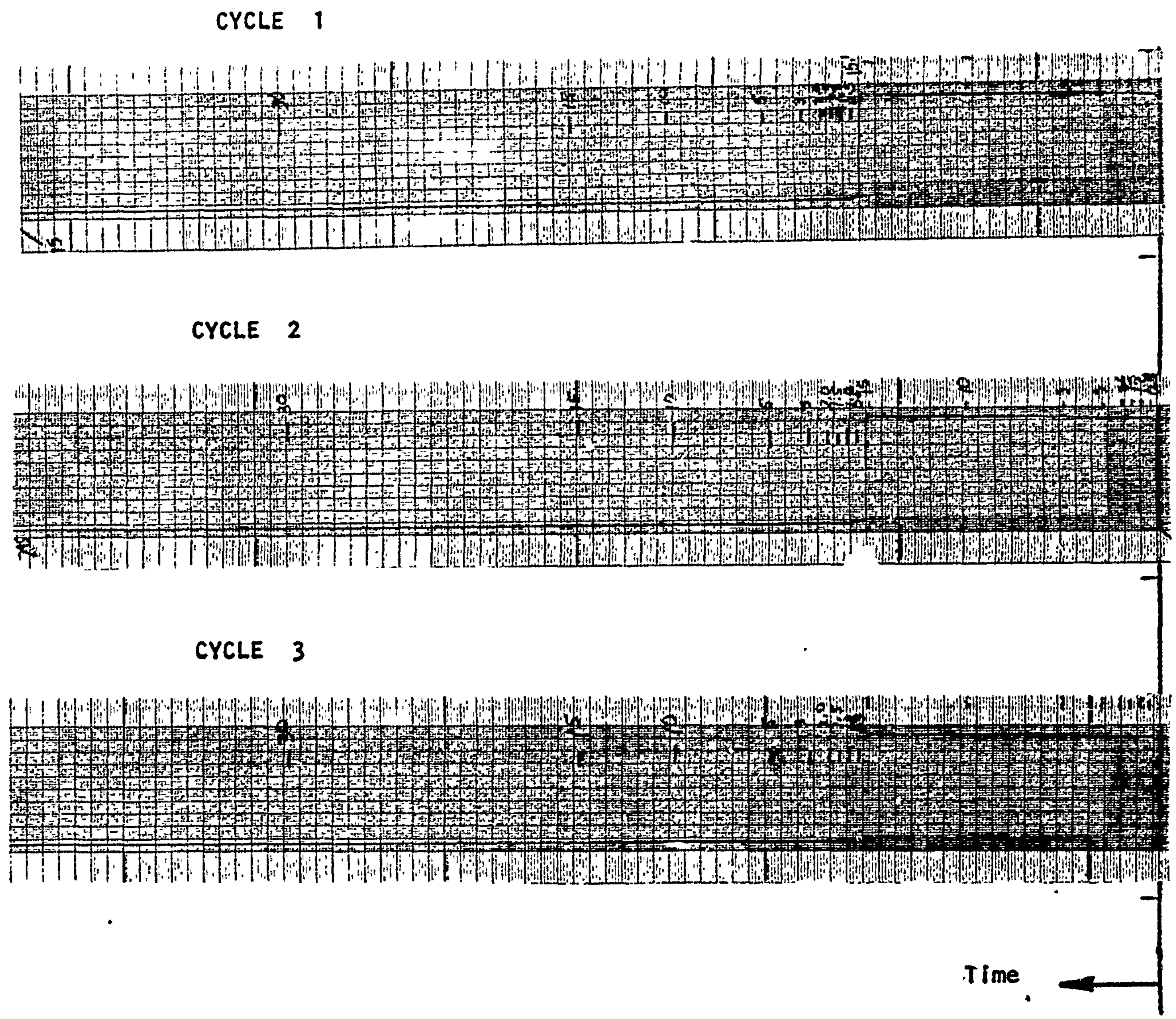


FIGURE 11-38 CREEP-RECOVERY CURVES FOR $+45^{\circ}$ SPECIMENS AT $170^{\circ}F$/60 % RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

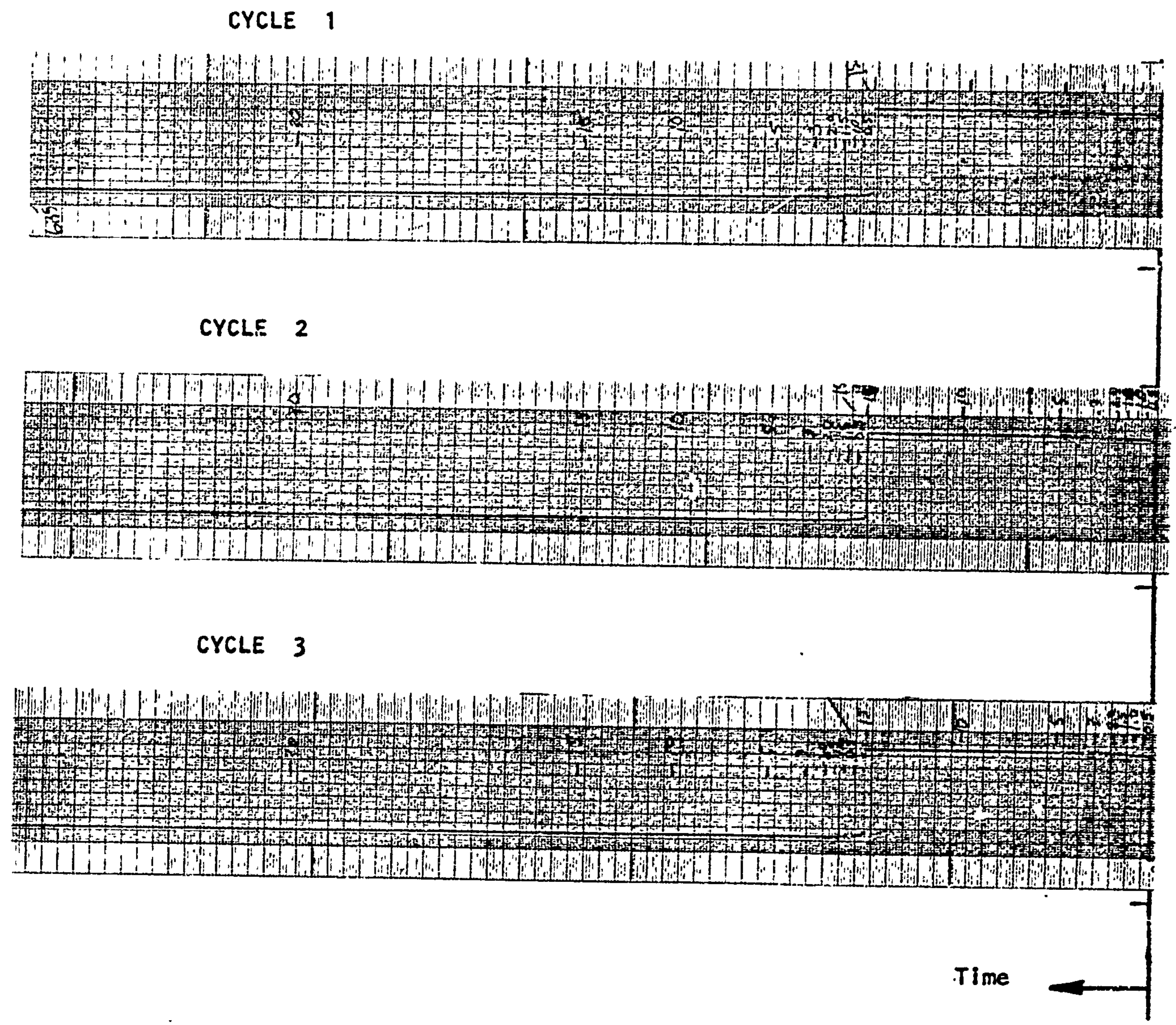


FIGURE 11-39 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 75 $^{\circ}$F/ 60 % RH ENVIRONMENT AND % ULTIMATE LOAD LEVEL

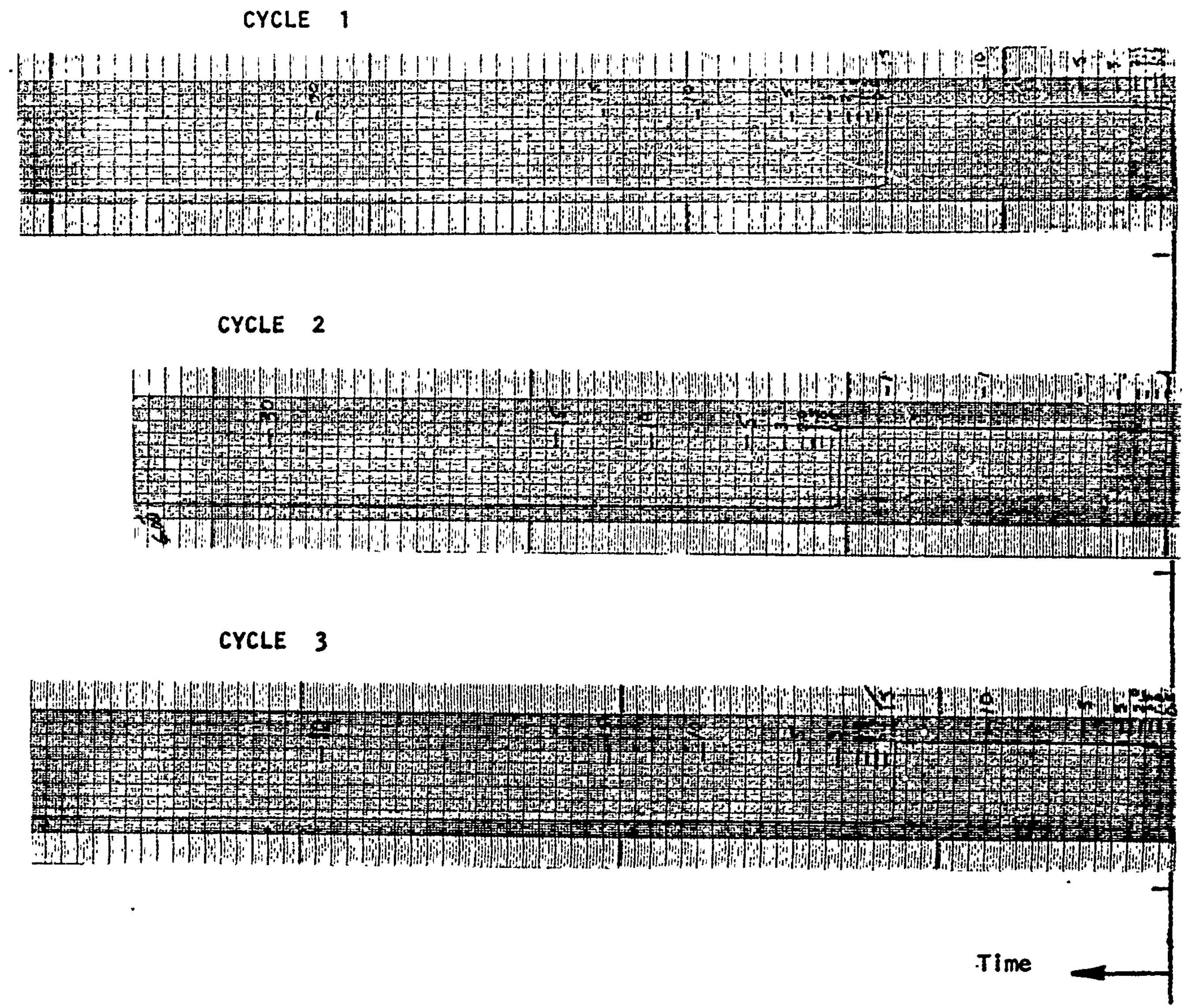


FIGURE 11-40 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120^{\circ}F/60\%$ RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

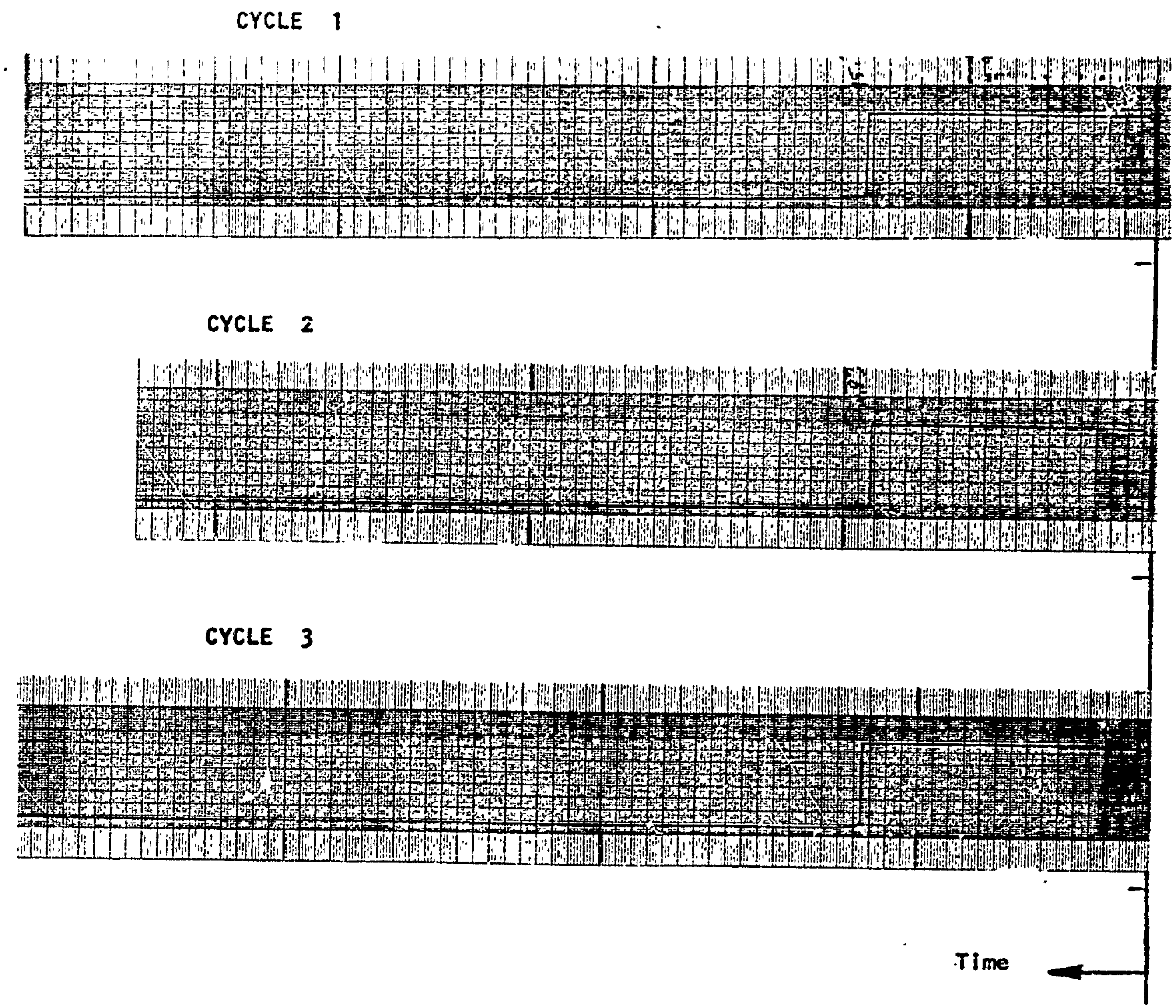


FIGURE 11-41 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 150 °F/60 % RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

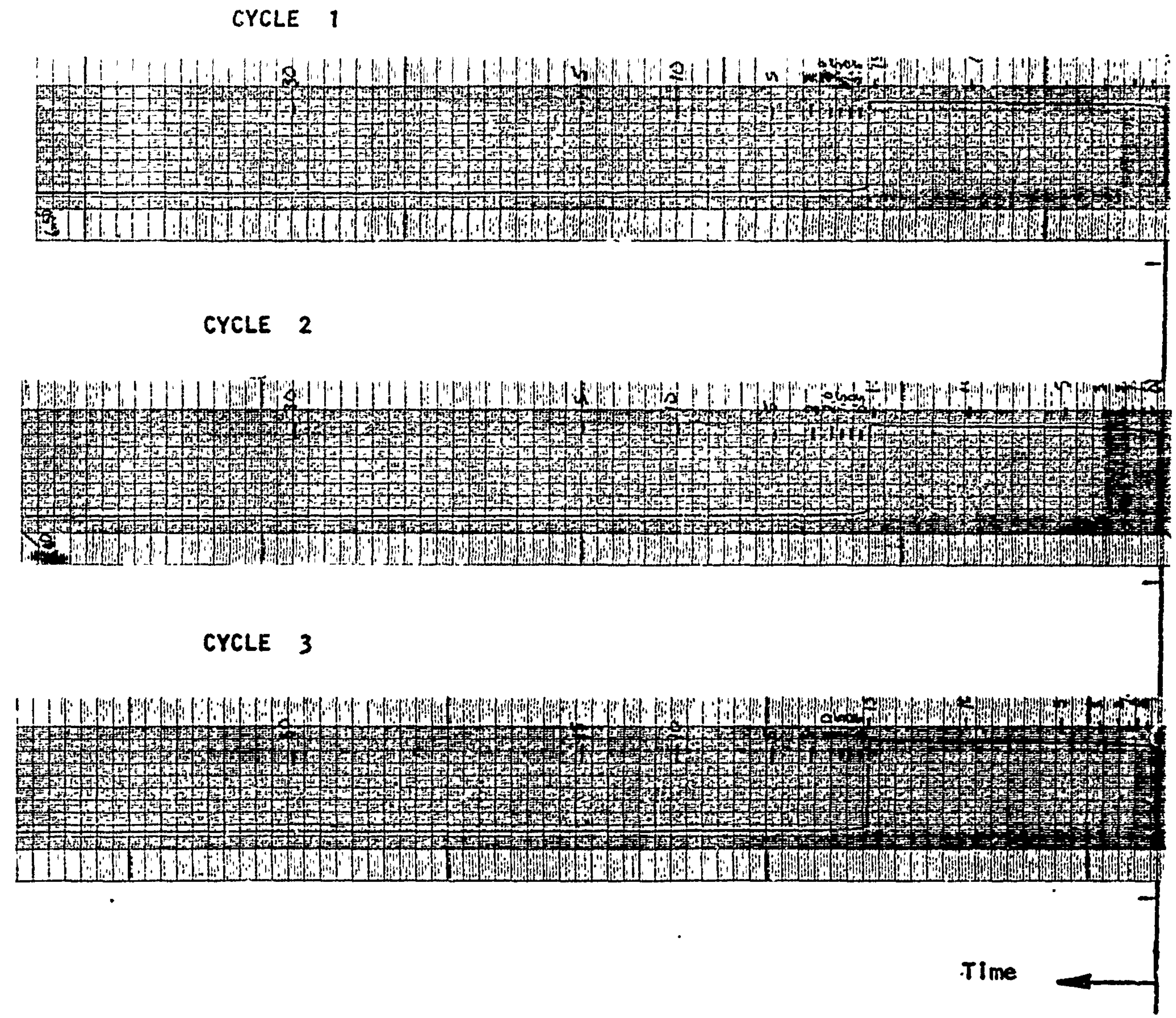


FIGURE 11-42 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $170\ ^{\circ}F/60\ \%$ RH ENVIRONMENT AND 40% ULTIMATE LOAD LEVEL

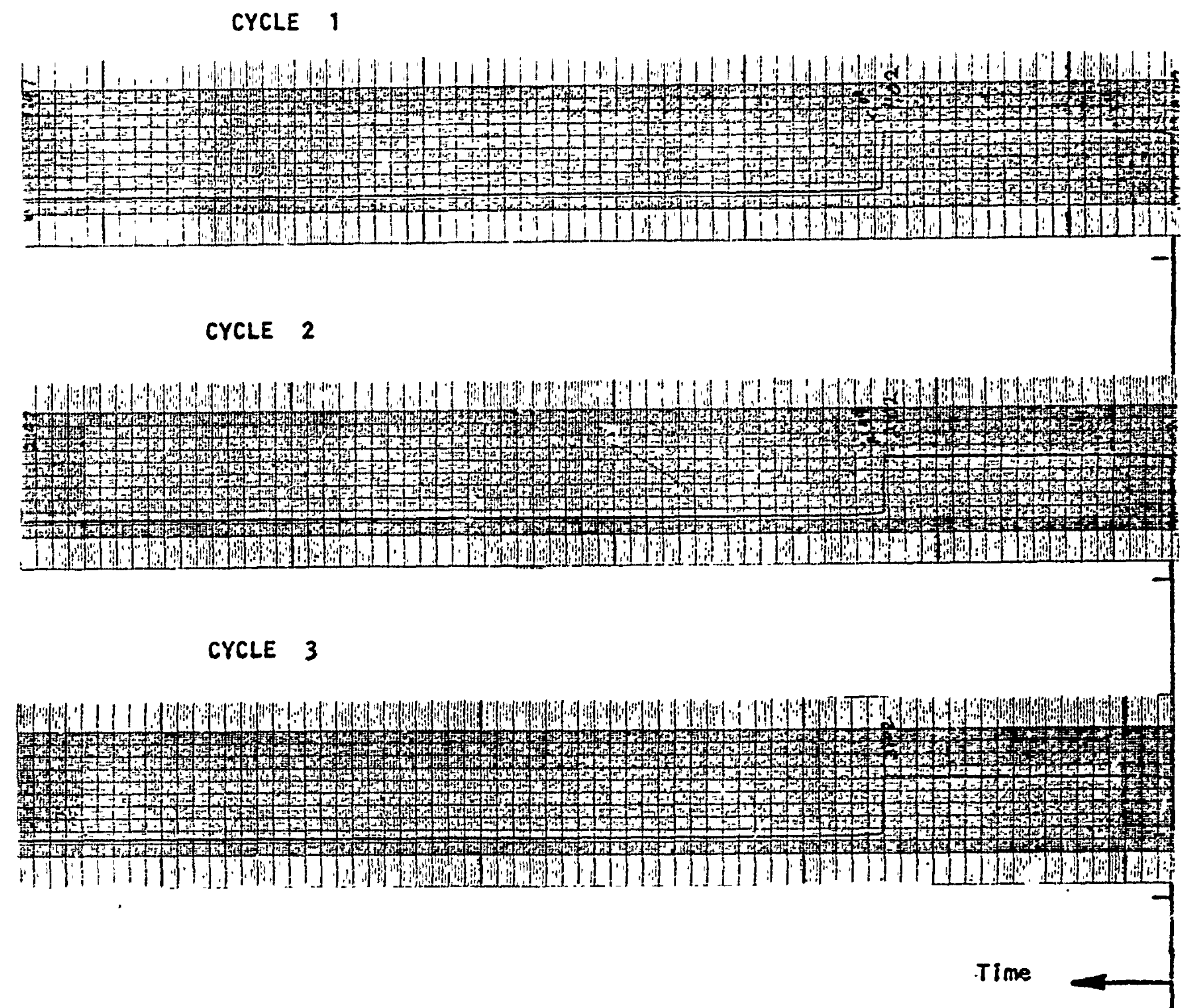


FIGURE 11-43 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $75\,^{\circ}F/60\,\%$ RH ENVIRONMENT AND 80 % ULTIMATE LOAD LEVEL

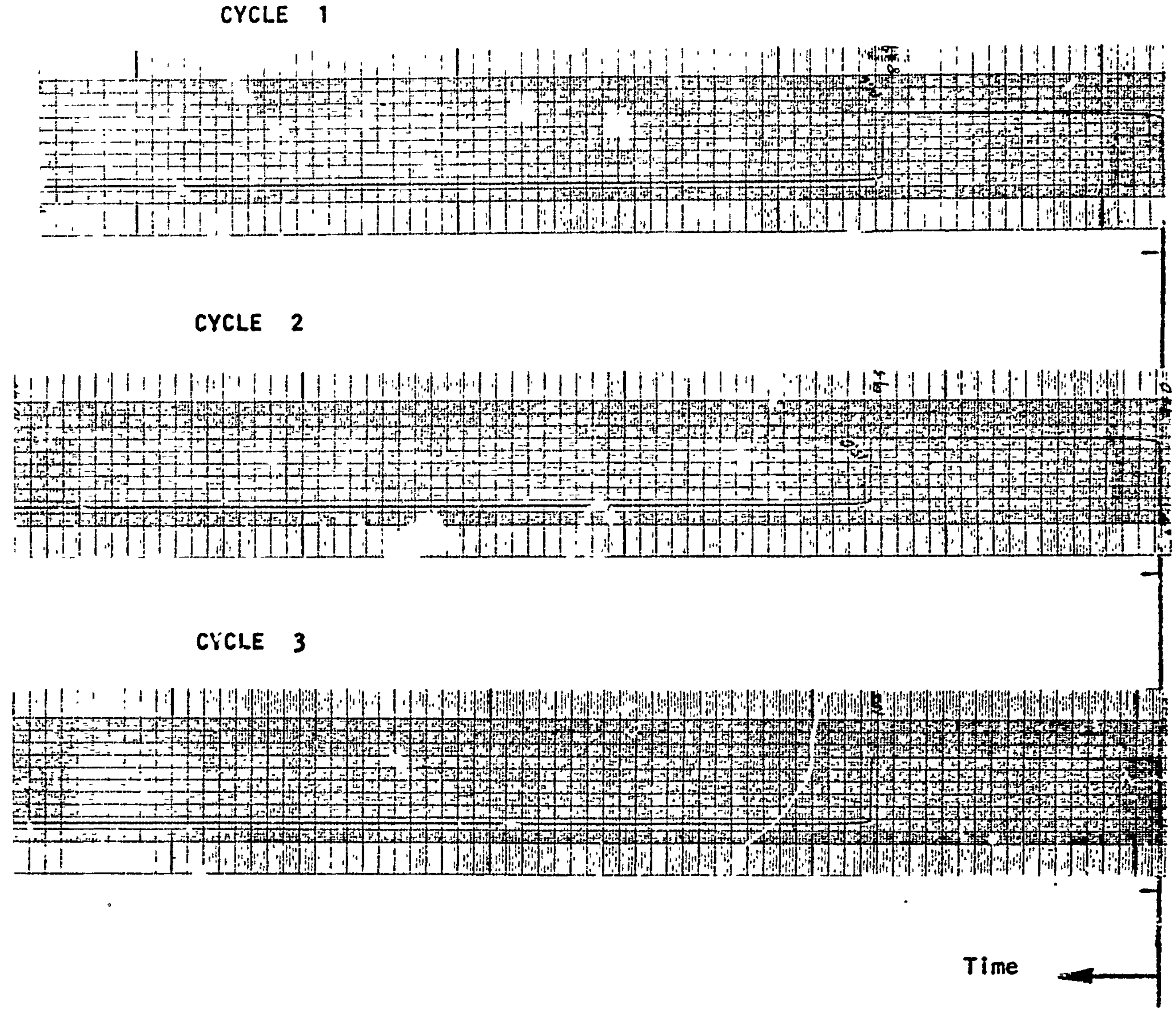


FIGURE 11-44 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 120 °F/60 % RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

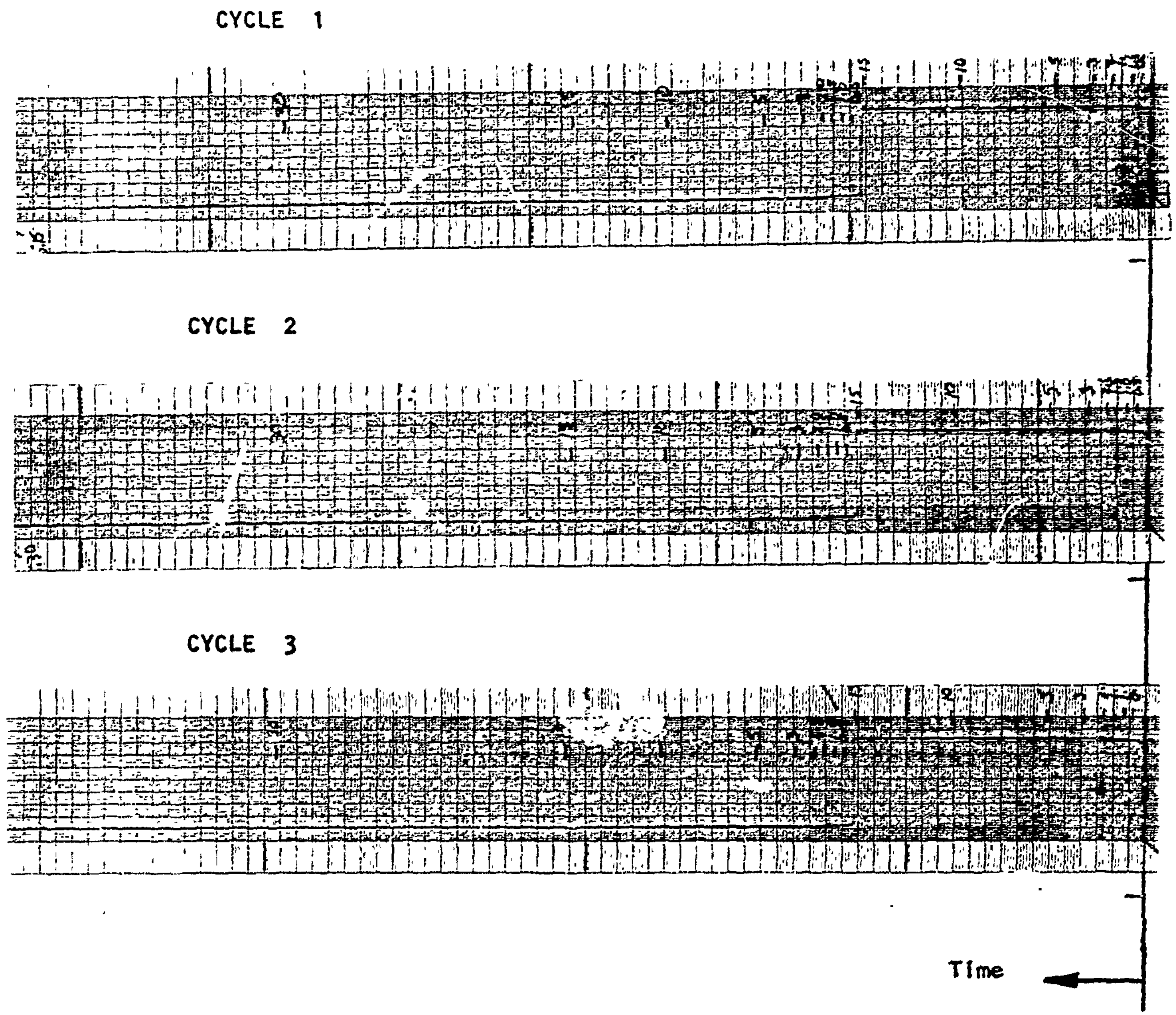


FIGURE II-45 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 75 $^{\circ}$F/95 % RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

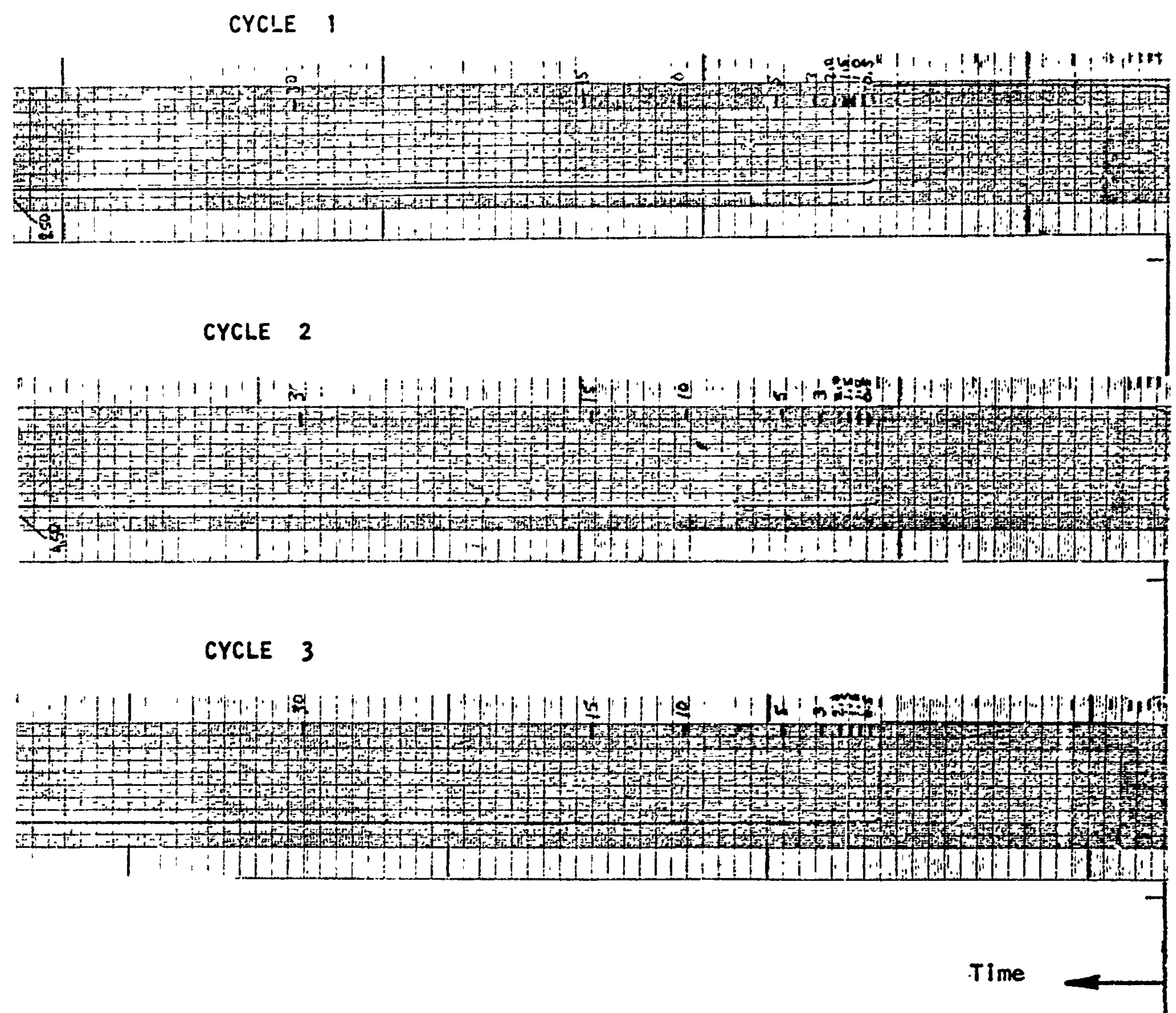


FIGURE 11-46 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120\,^{\circ}F/95\,\%$ RH ENVIRONMENT AND 20 % ULTIMATE LOAD LEVEL

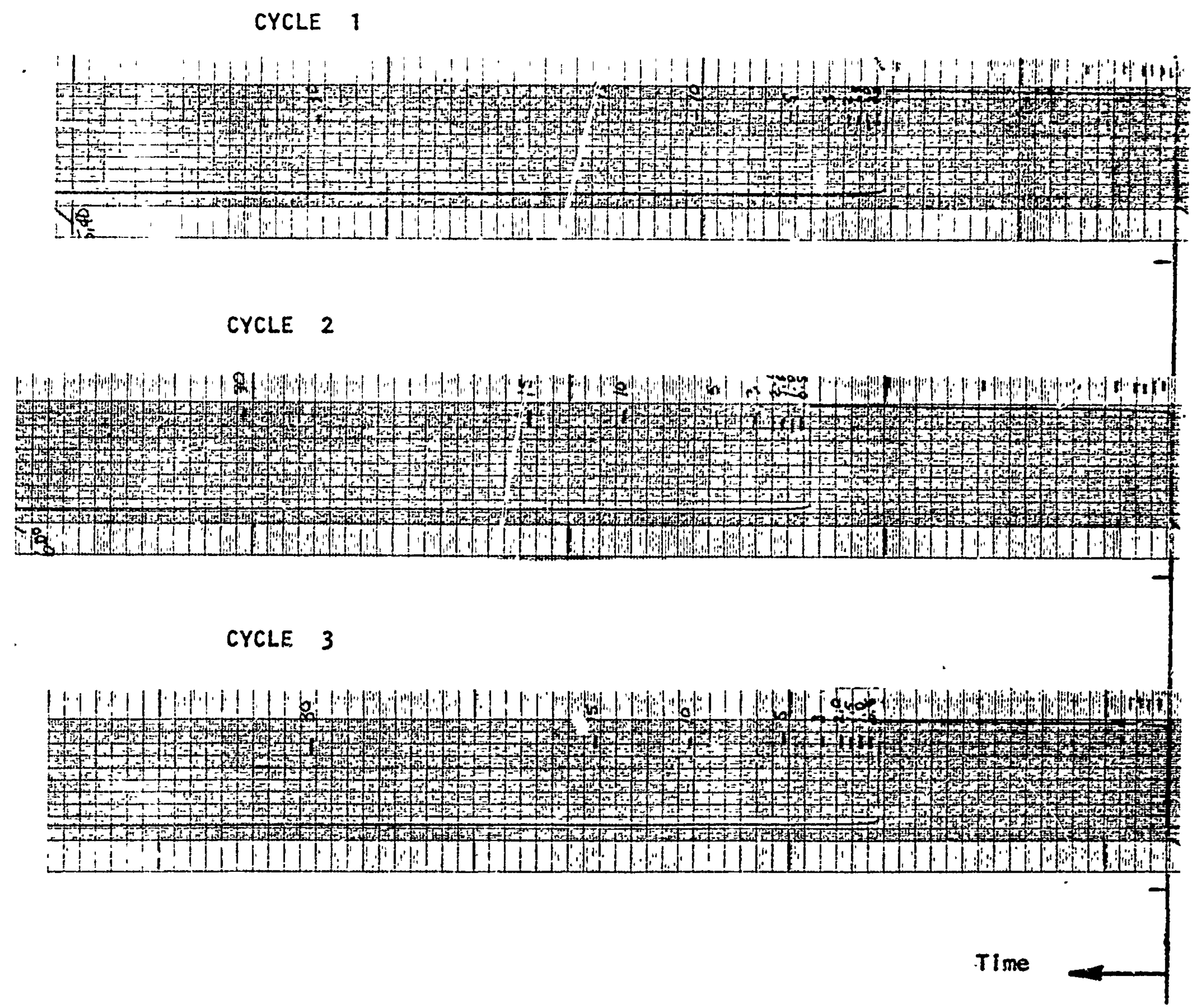


FIGURE 11-47 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 150 $^{\circ}$F/95 % RH ENVIRONMENT AND 20% ULTIMATE LOAD LEVEL

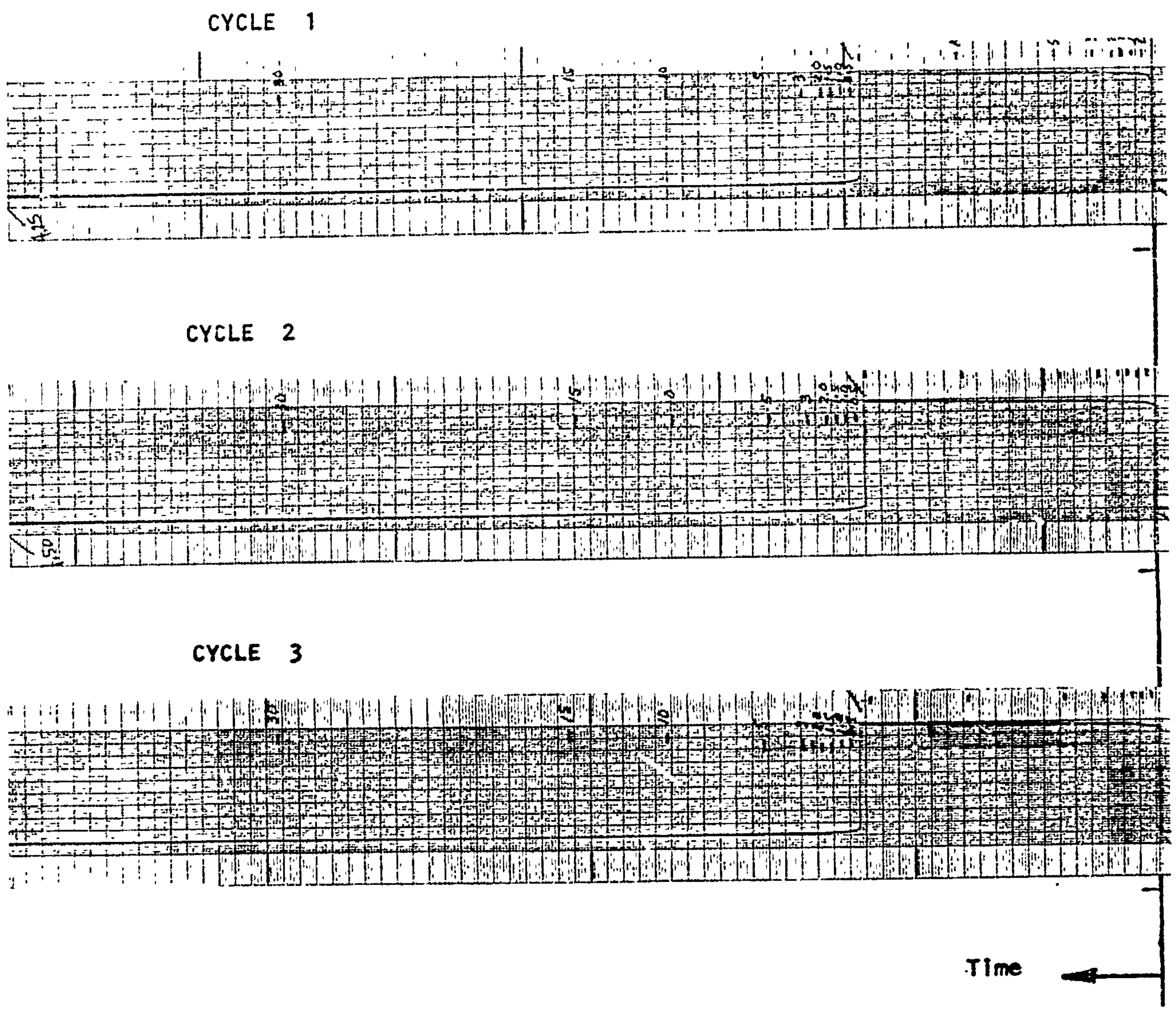


FIGURE 11-48 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $170^{\circ}F$/ 95 % RH ENVIRONMENT AND % ULTIMATE LOAD LEVEL

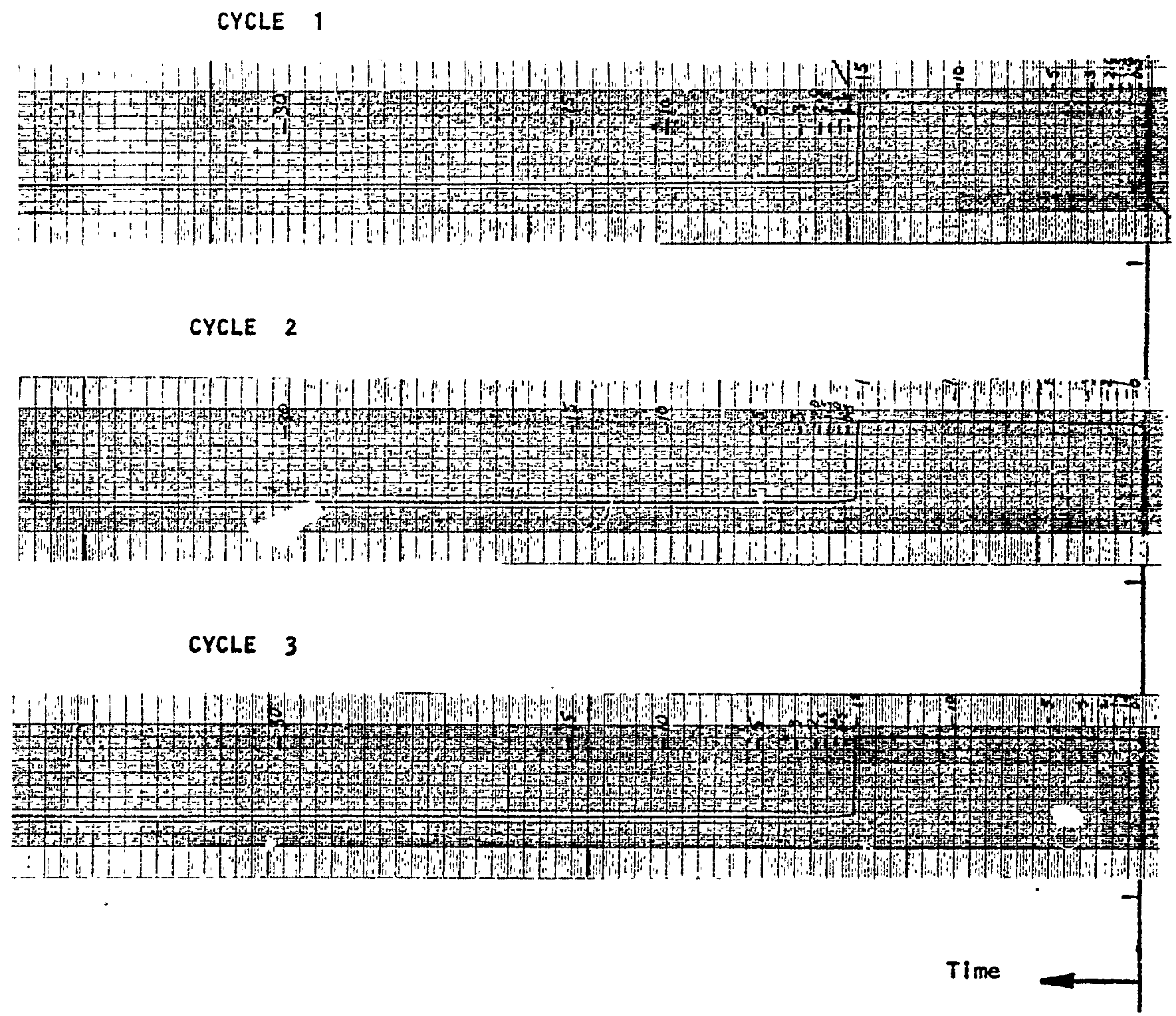


FIGURE 11-49 CREEP-RECOVERY CURVES FOR $\underline{+}45^{\circ}$ SPECIMENS AT $75^{\circ}F/95\%$ RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

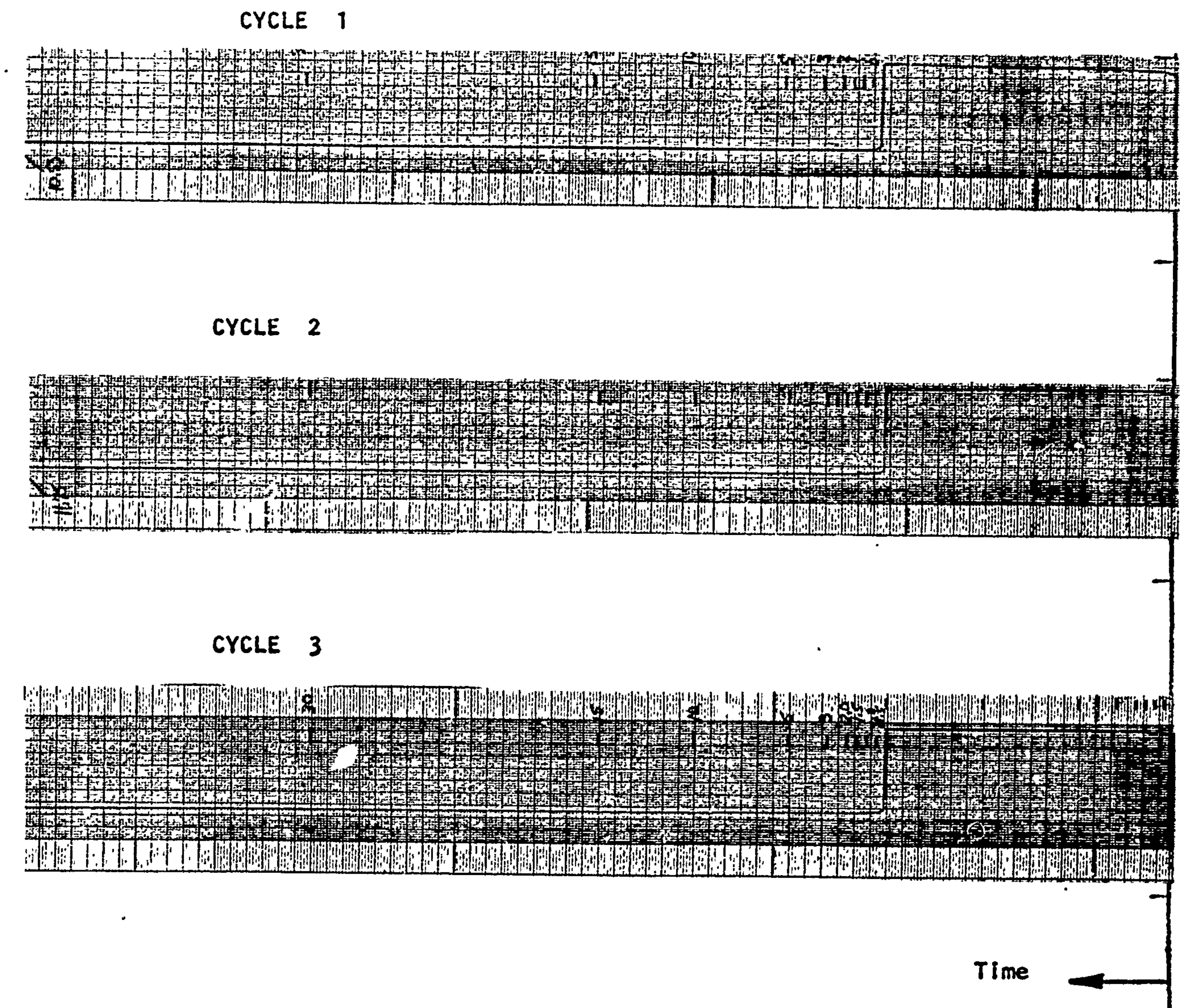


FIGURE 11-50 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $120^{\circ}F/95\%$ RH ENVIRONMENT AND 40% ULTIMATE LOAD LEVEL

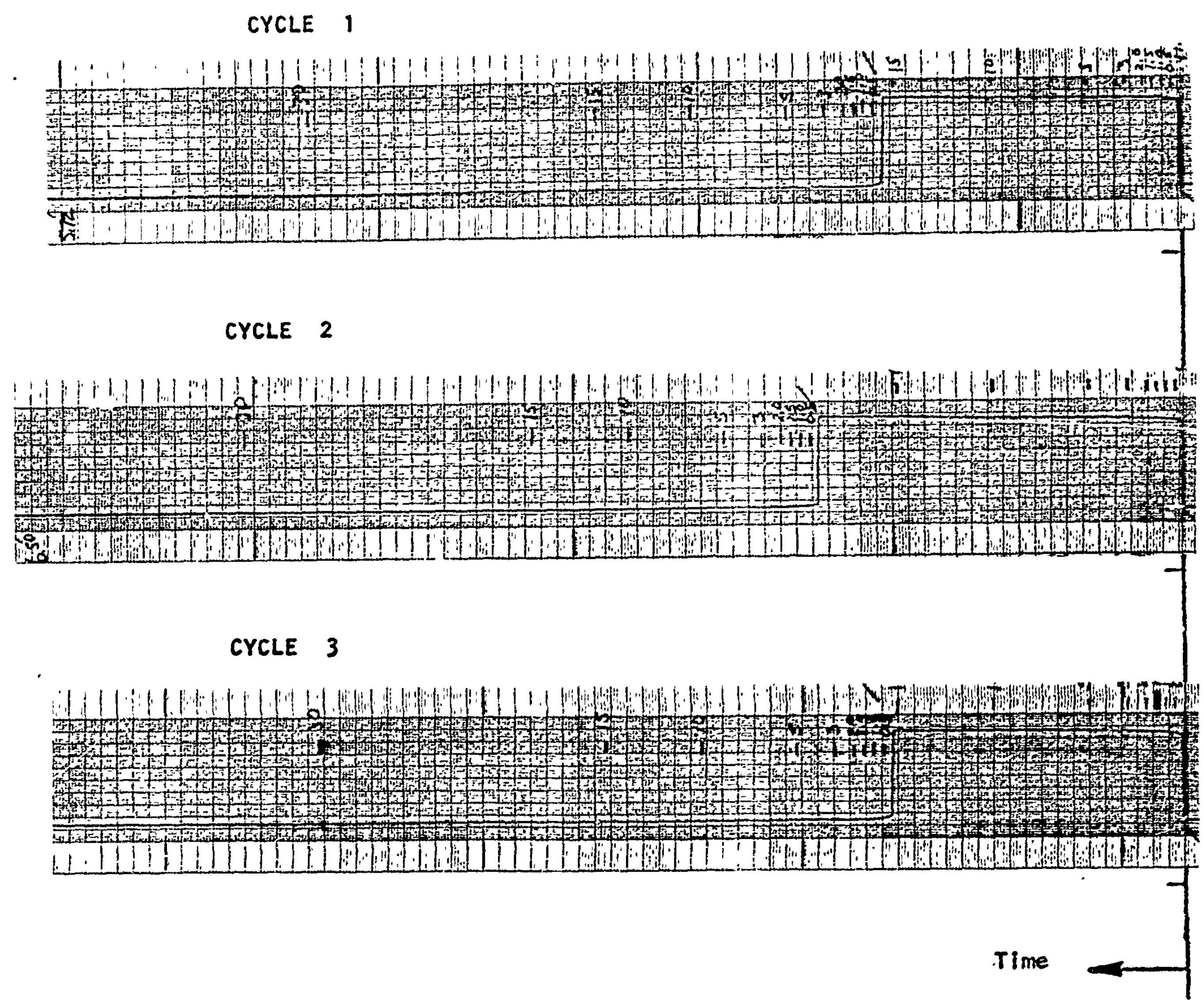


FIGURE 11-51 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT $150^{\circ}F$/ 95% RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

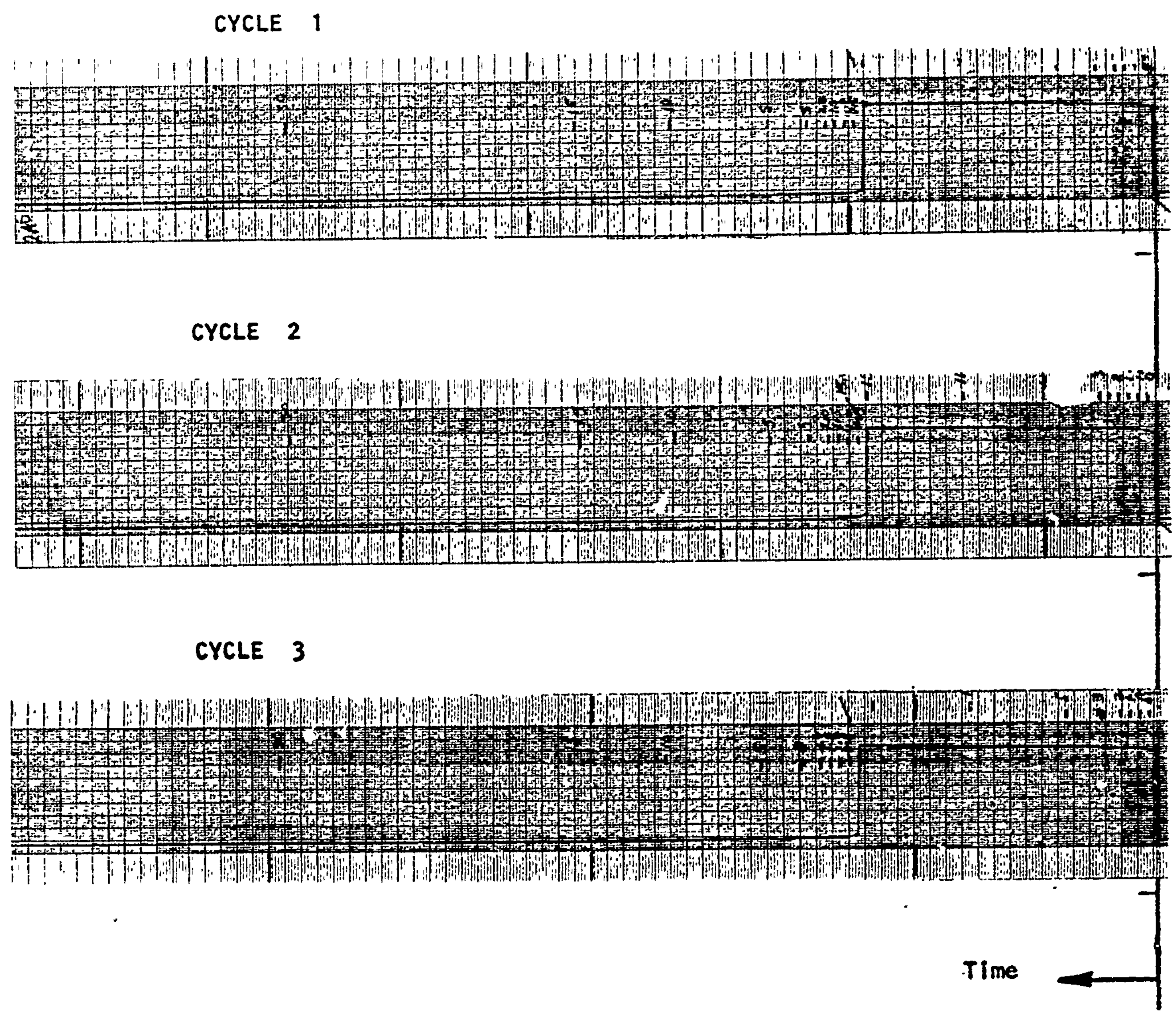


FIGURE 11-52 CREEP-RECOVERY CURVES FOR +45° SPECIMENS AT 170°F/ 95 % RH ENVIRONMENT AND 40 % ULTIMATE LOAD LEVEL

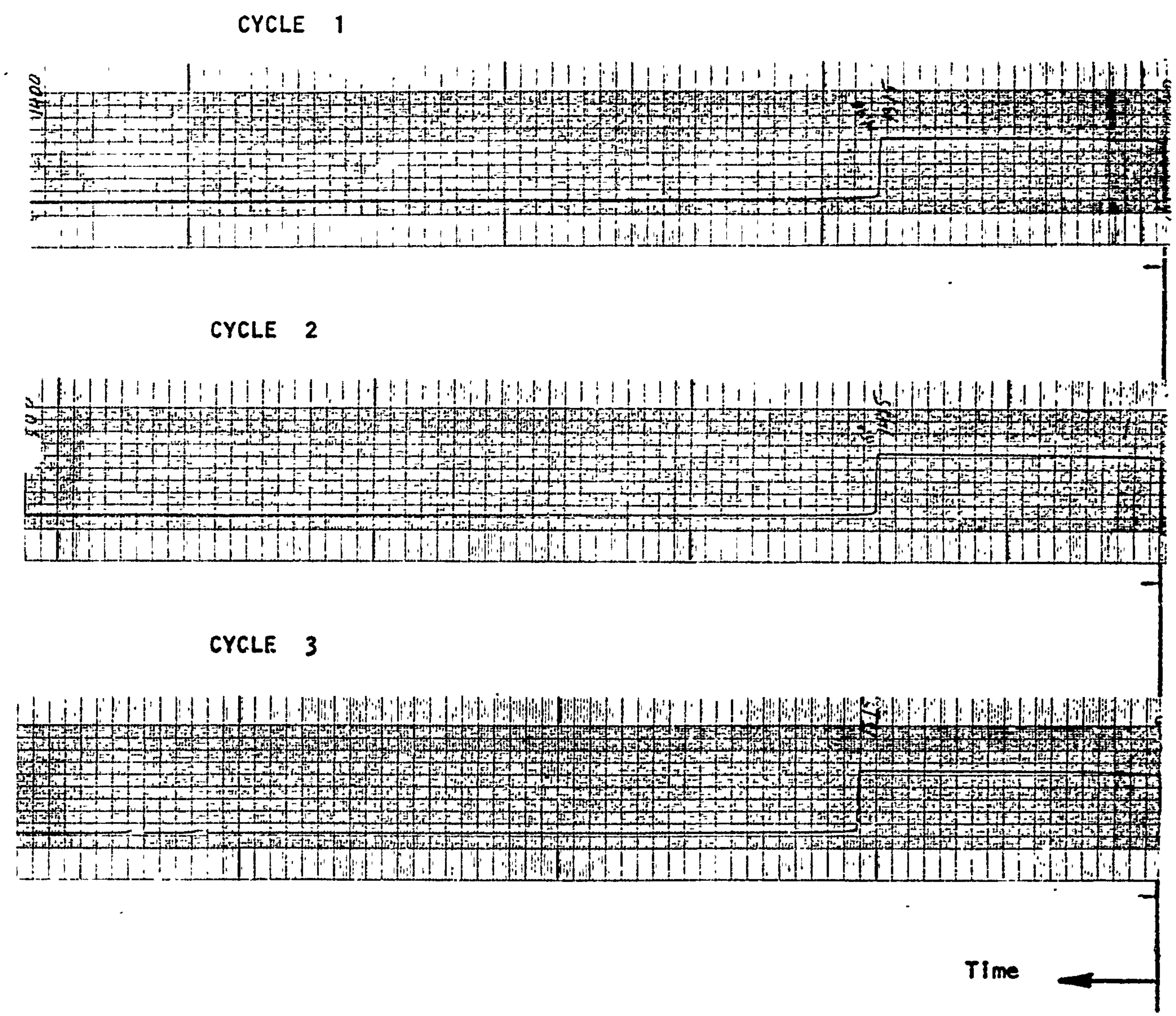


FIGURE 11-53 CREEP-RECOVERY CURVES FOR $\pm 45^{\circ}$ SPECIMENS AT 75 °F/95 % RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

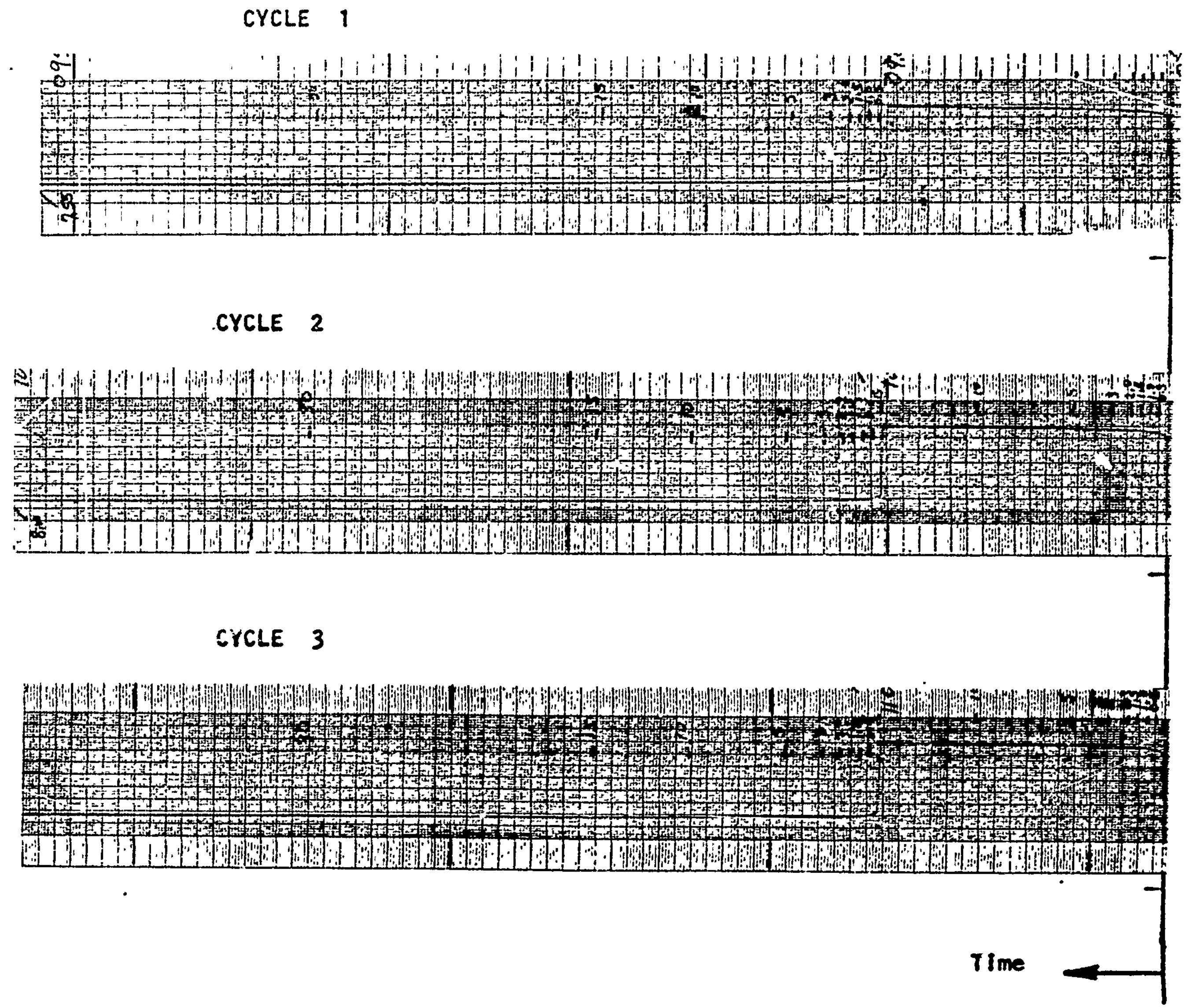


FIGURE 11-54 CREEP-RECOVERY CURVES FOR $+45^{\circ}$ SPECIMENS AT 120 $^{\circ}F$/95 % RH ENVIRONMENT AND 60 % ULTIMATE LOAD LEVEL

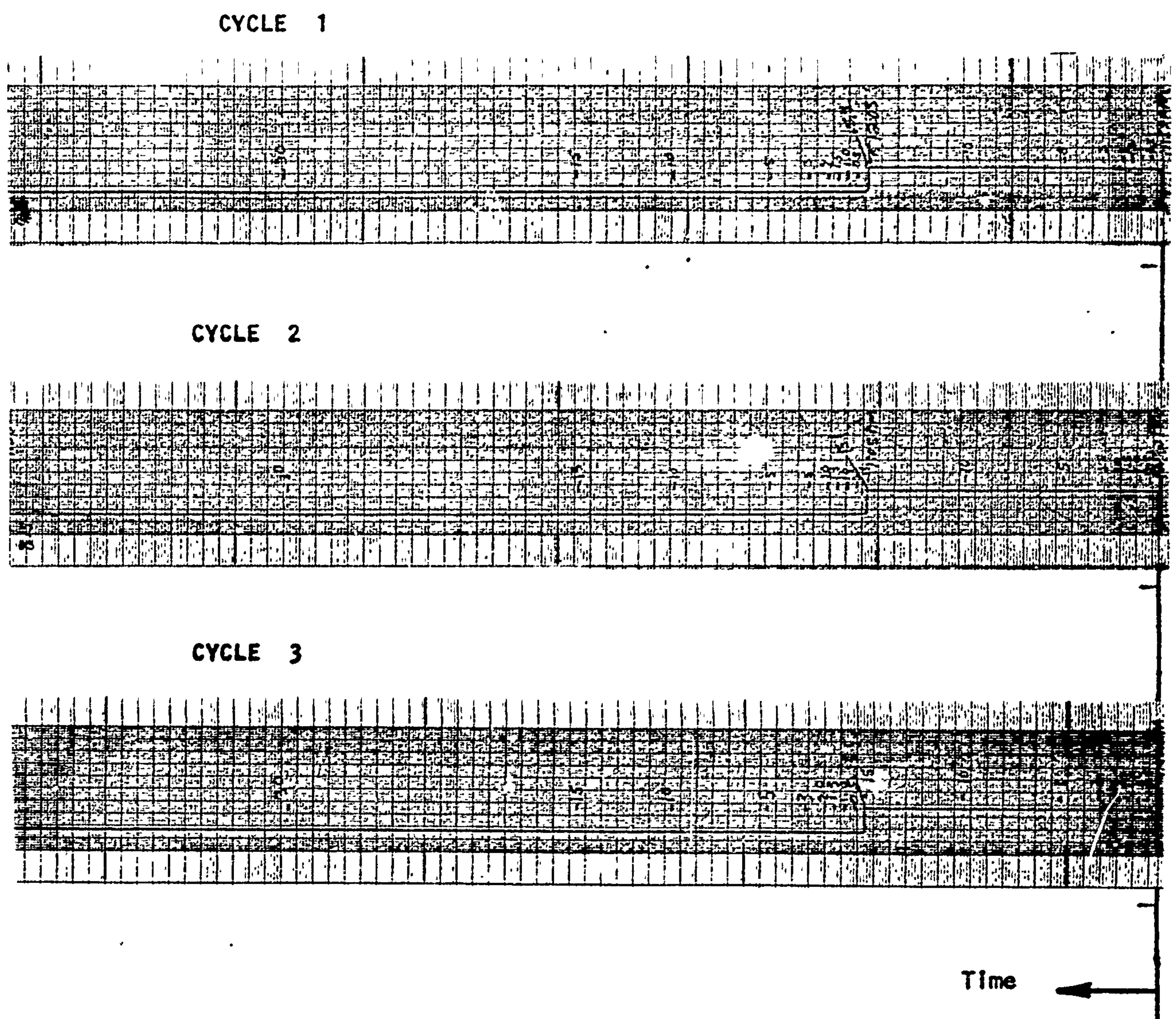


FIGURE 11-55 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 75 °F/dry% RH ENVIRONMENT AND 25 % ULTIMATE LOAD LEVEL

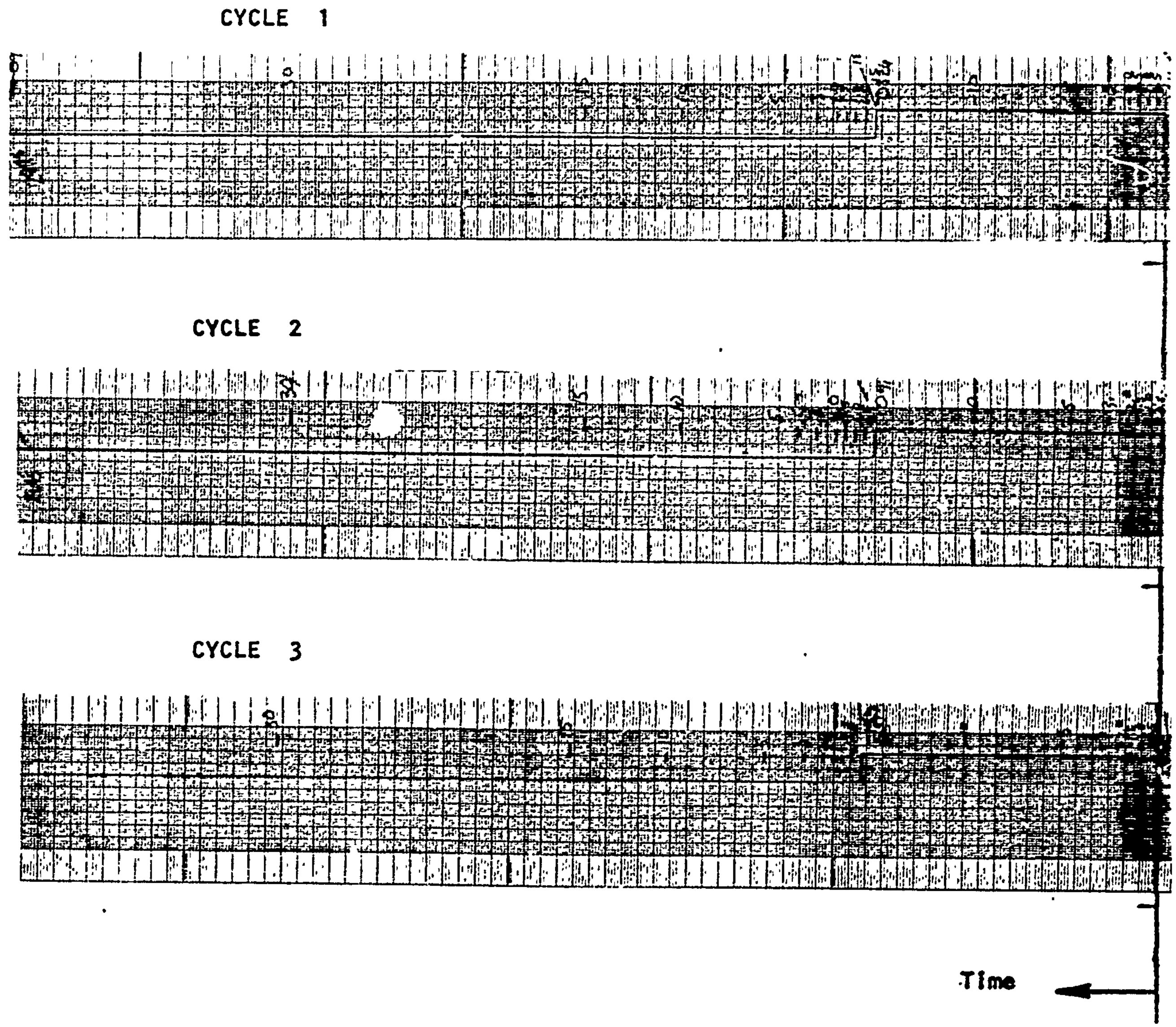


FIGURE 11-56 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 120°F/dry % RH ENVIRONMENT AND 25 % ULTIMATE LOAD LEVEL

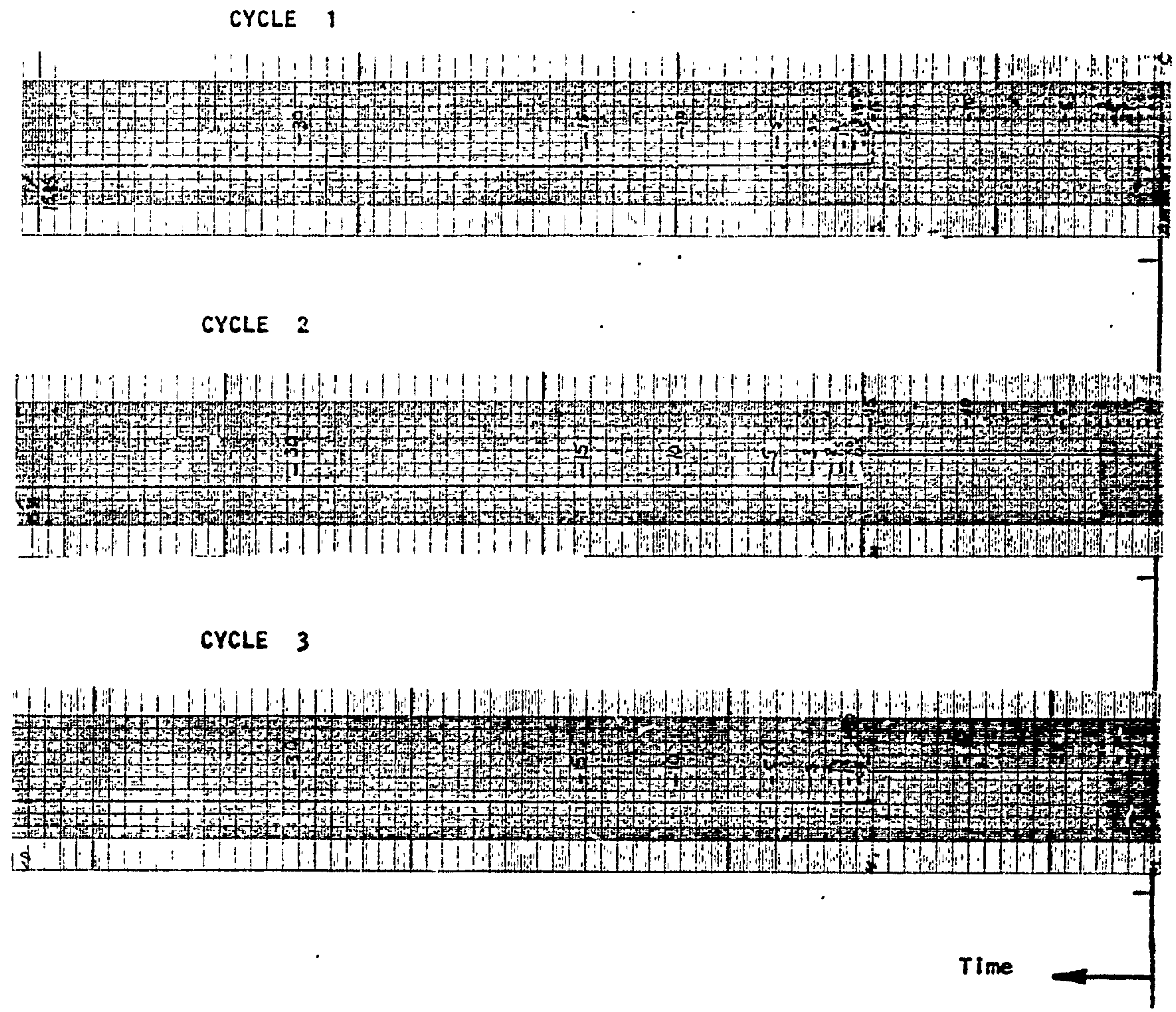


FIGURE 11-57 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 150 °F/dry% RH ENVIRONMENT AND 25 % ULTIMATE LOAD LEVEL

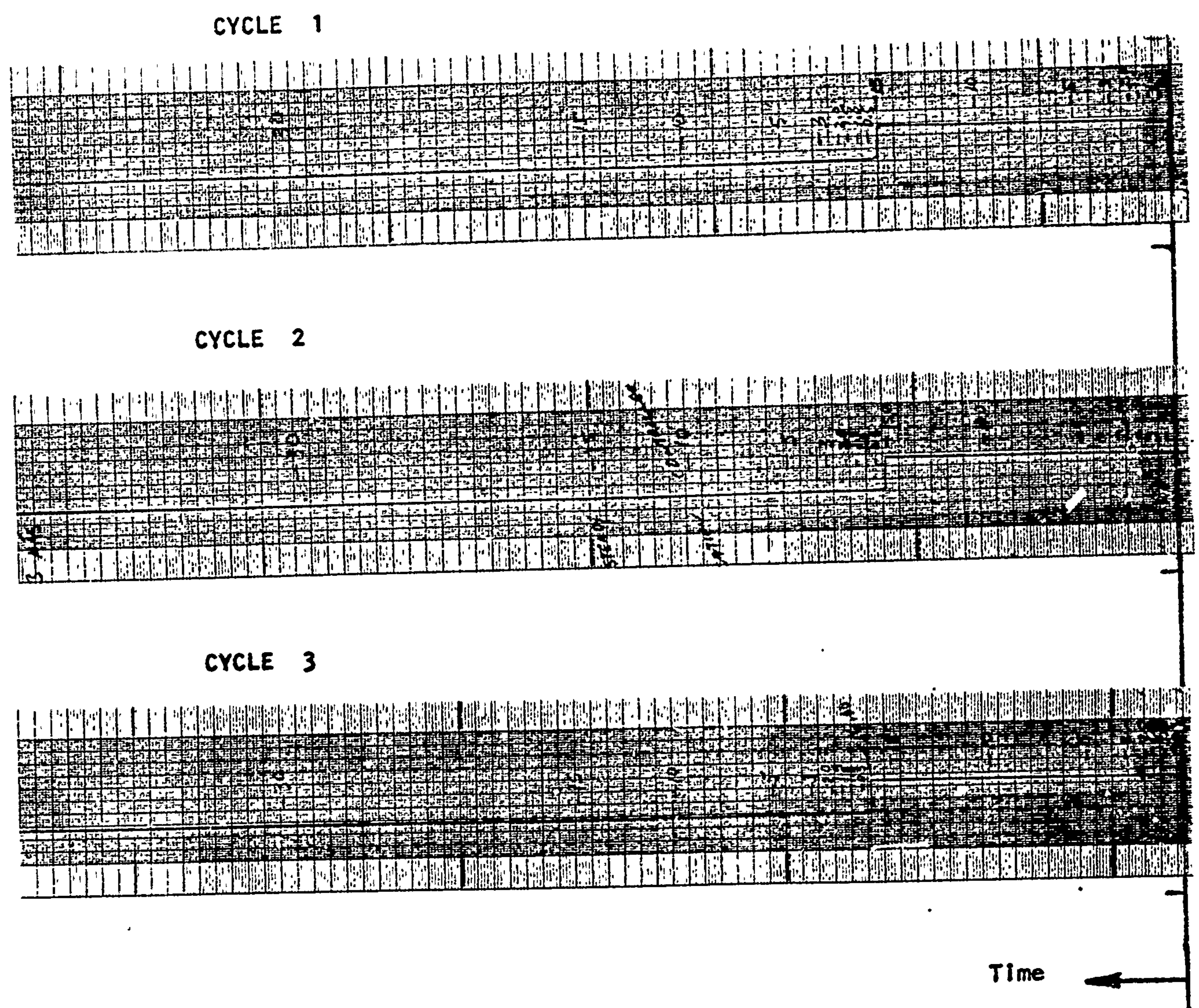


FIGURE 11-58 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 170 °F/dry% RH ENVIRONMENT AND 25 % ULTIMATE LOAD LEVEL

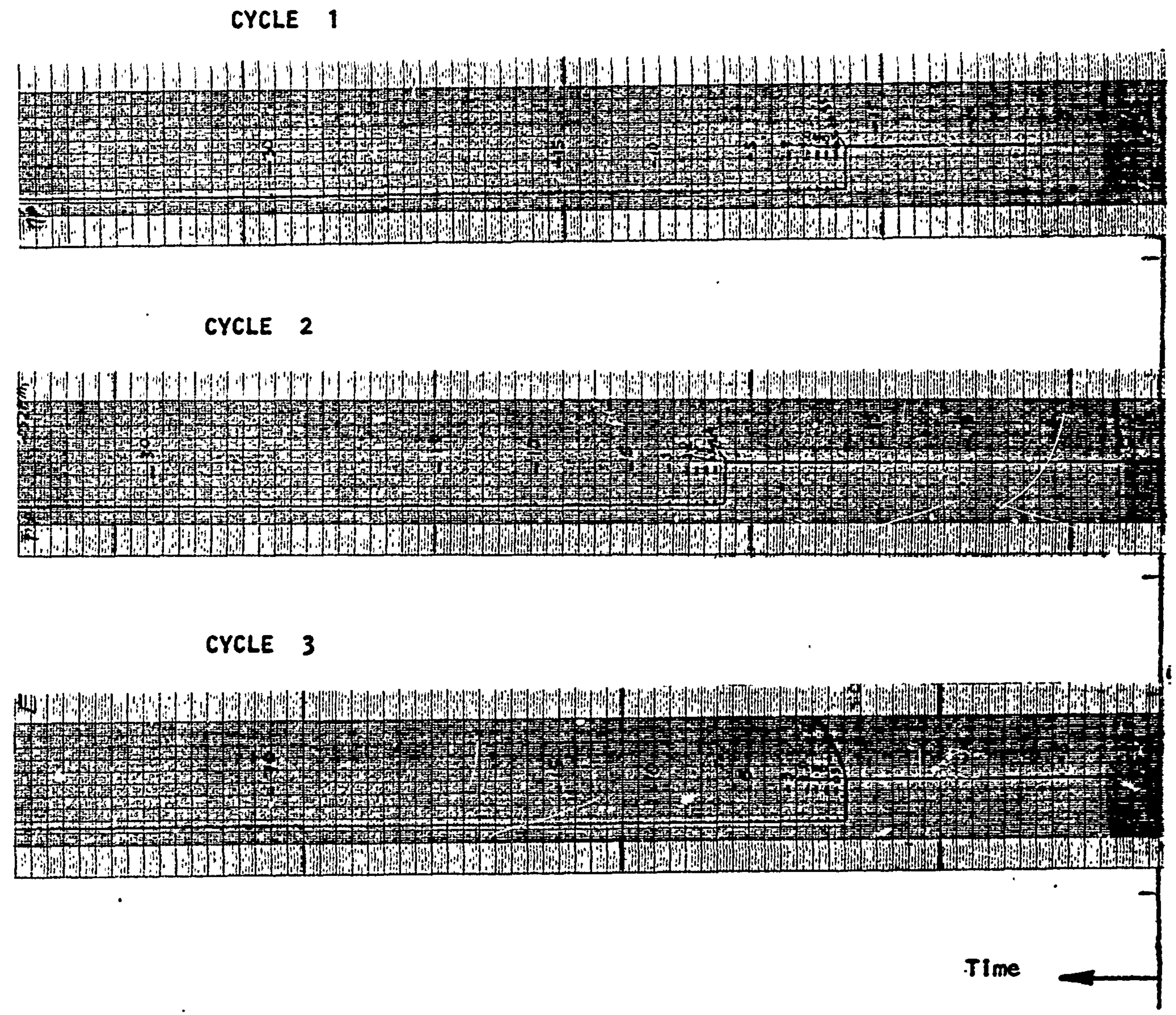


FIGURE 11-59 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 75°F/dry % RH ENVIRONMENT AND 38 % ULTIMATE LOAD LEVEL

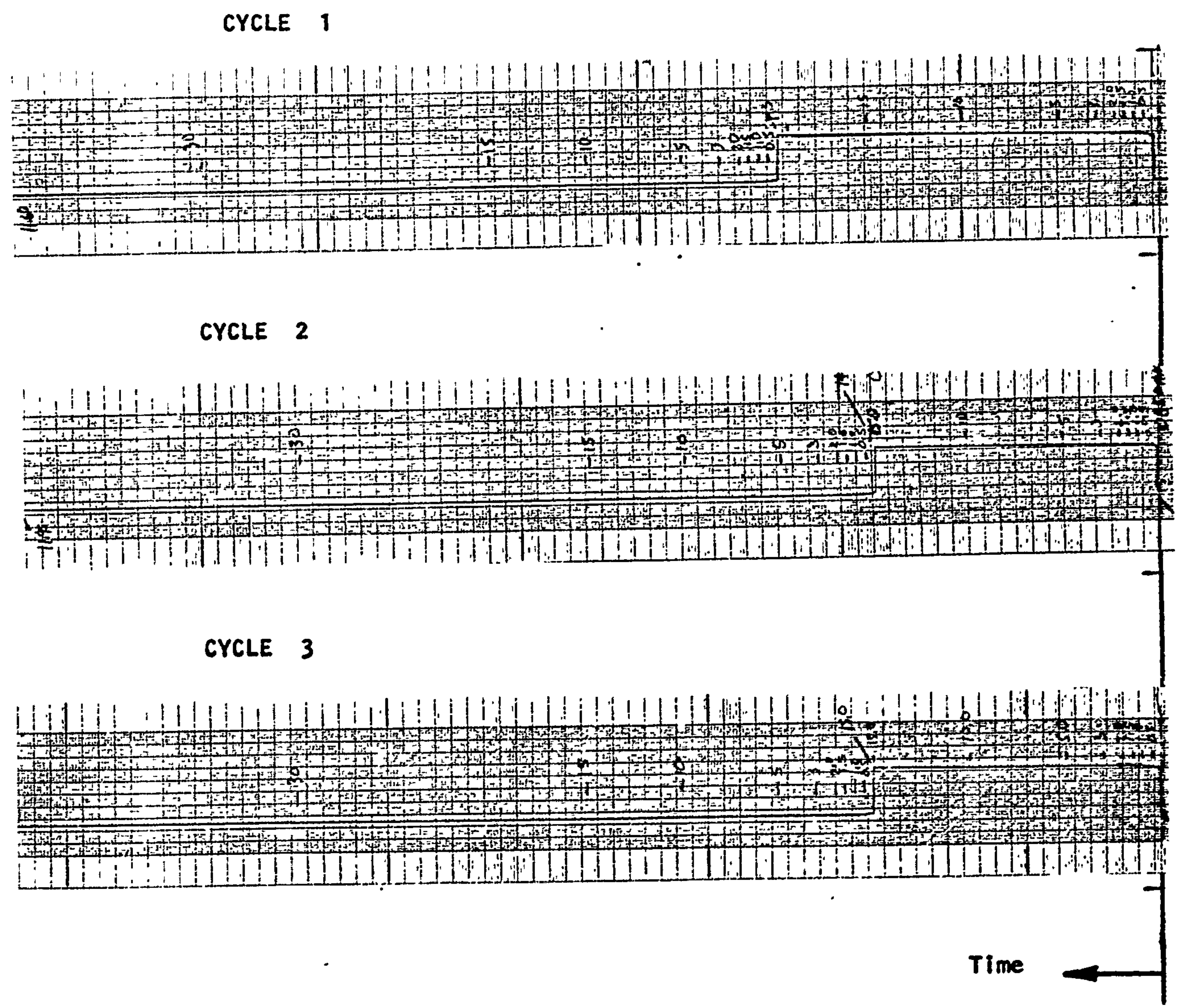


FIGURE 11-60 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 120°F/dry% RH ENVIRONMENT AND 38% ULTIMATE LOAD LEVEL

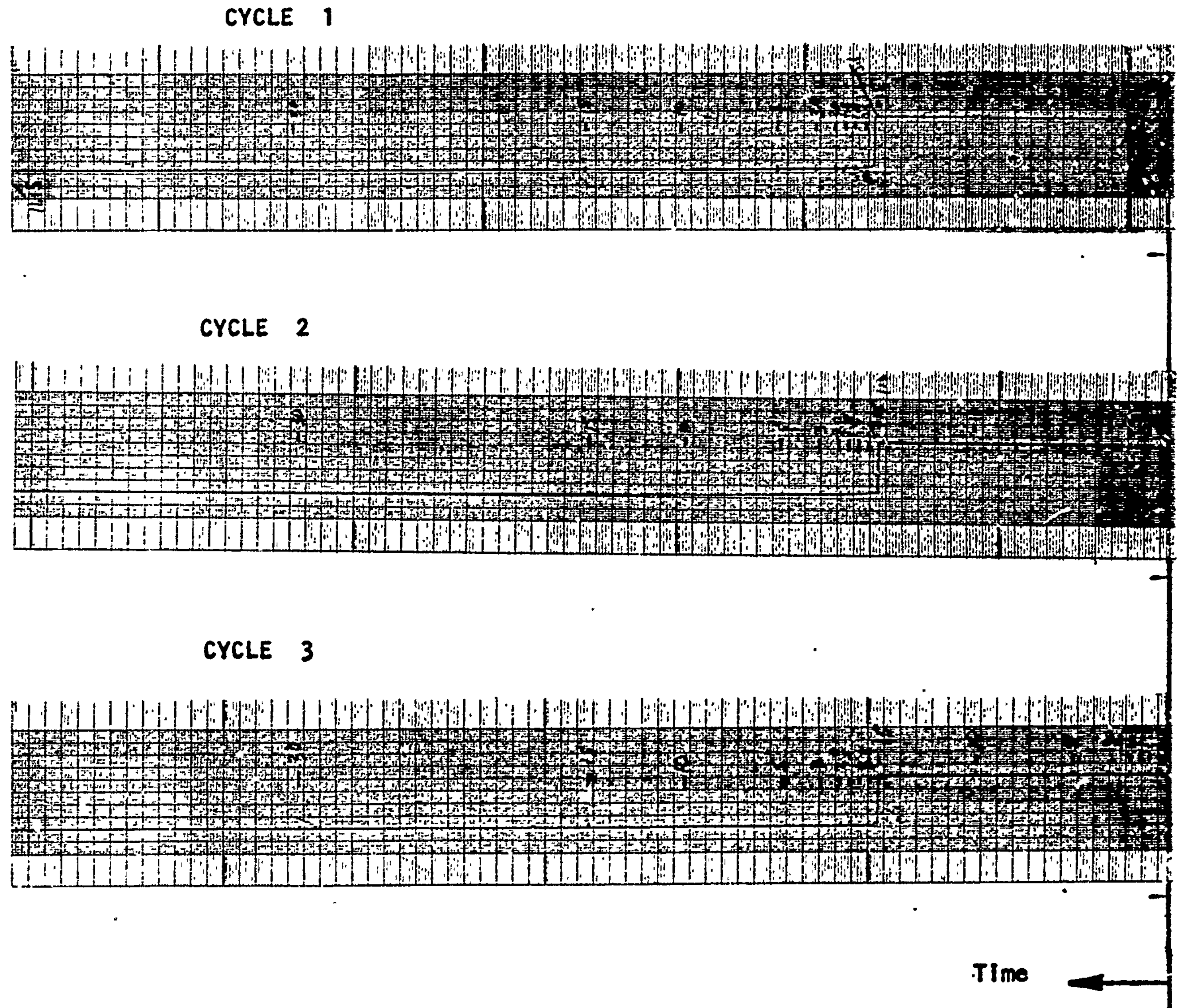


FIGURE 11-61 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 150 °F/dry% RH ENVIRONMENT AND 38 % ULTIMATE LOAD LEVEL

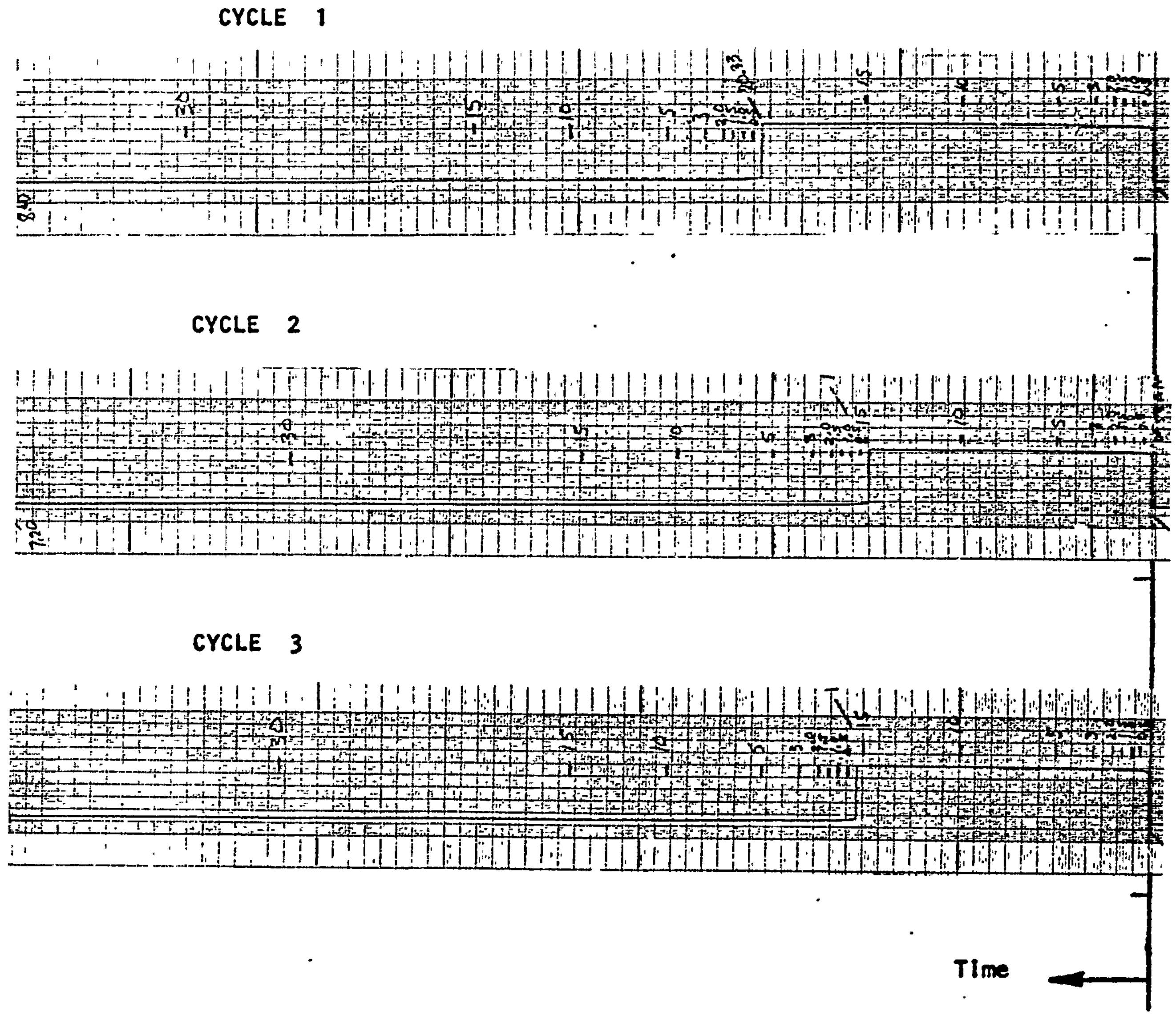


FIGURE 11-62 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 170 °F/dry% RH ENVIRONMENT AND 38 % ULTIMATE LOAD LEVEL

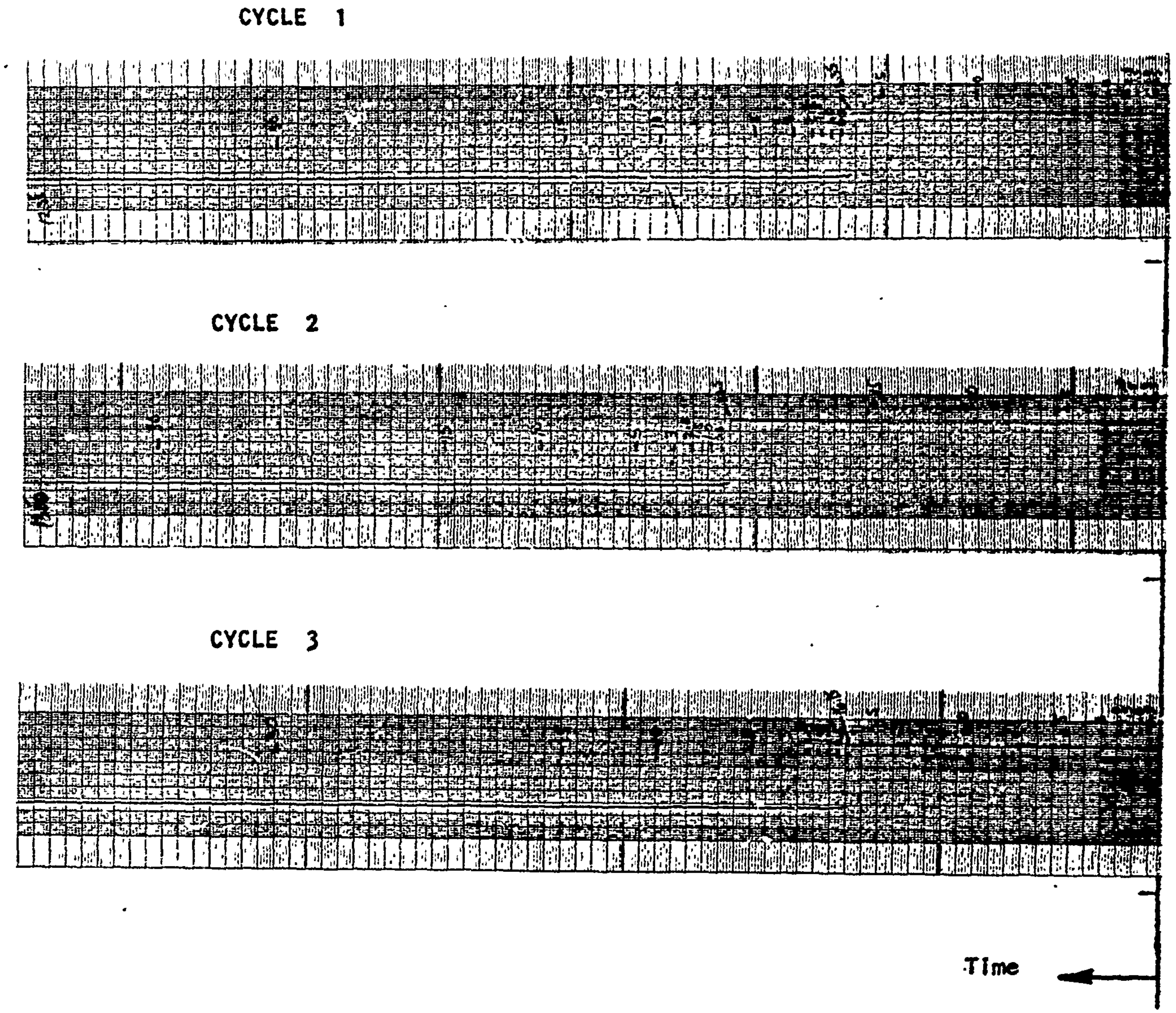


FIGURE 11-63 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 75°F/ dry% RH ENVIRONMENT AND 50 % ULTIMATE LOAD LEVEL

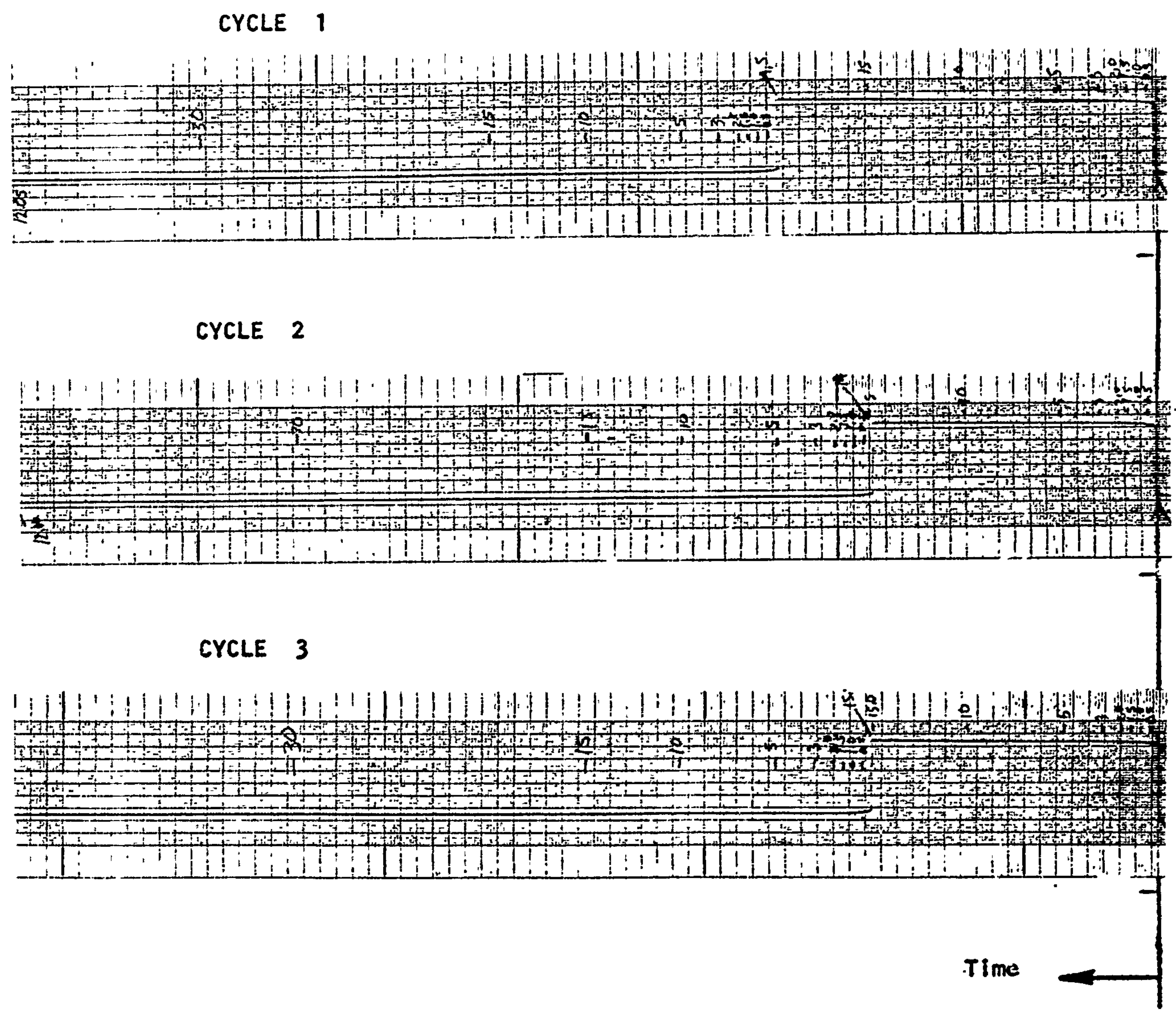


FIGURE 11-64 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 120°F/dry % RH ENVIRONMENT AND 50% ULTIMATE LOAD LEVEL

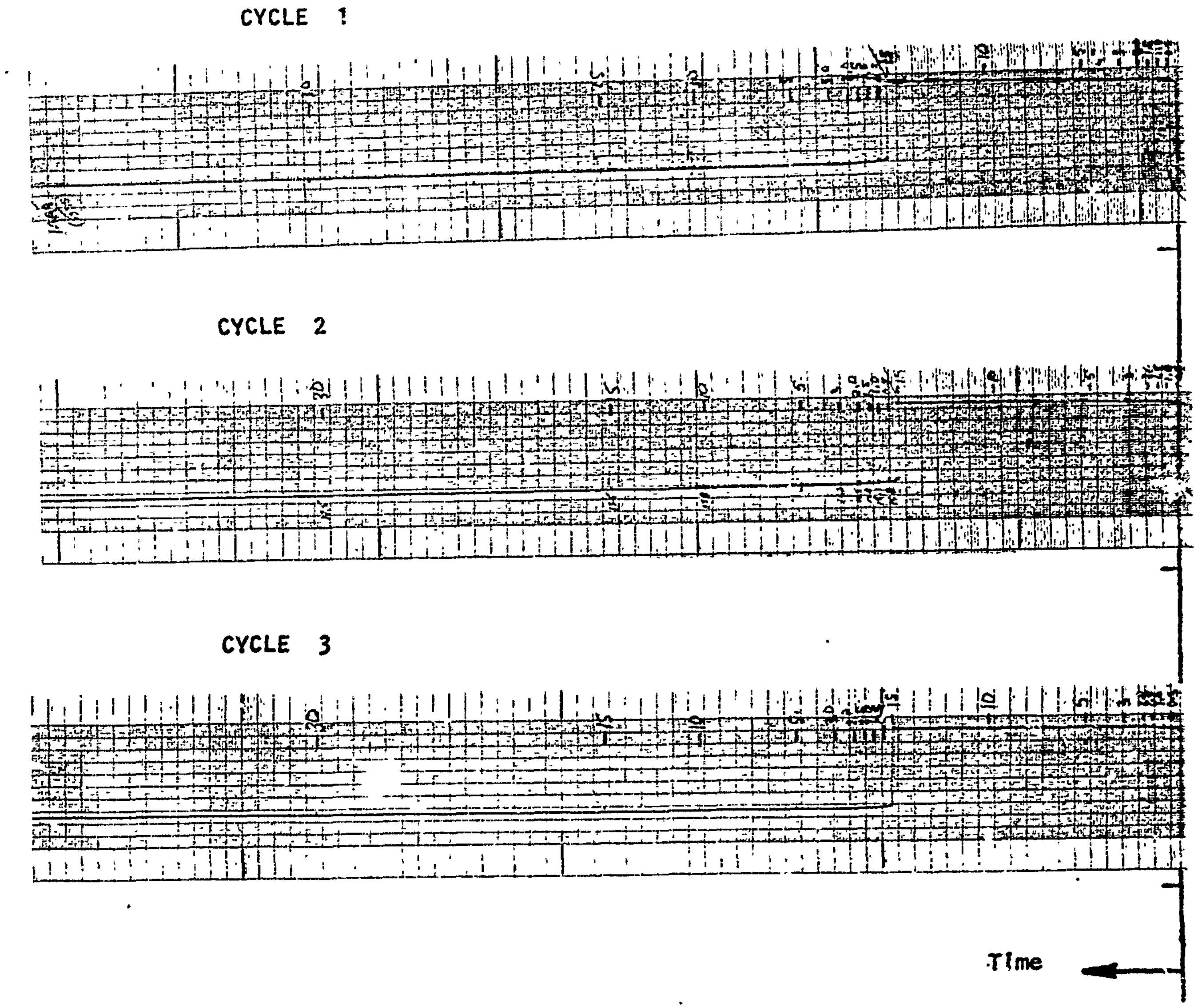


FIGURE 11-65 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 150°F/dry % RH ENVIRONMENT AND 50 % ULTIMATE LOAD LEVEL

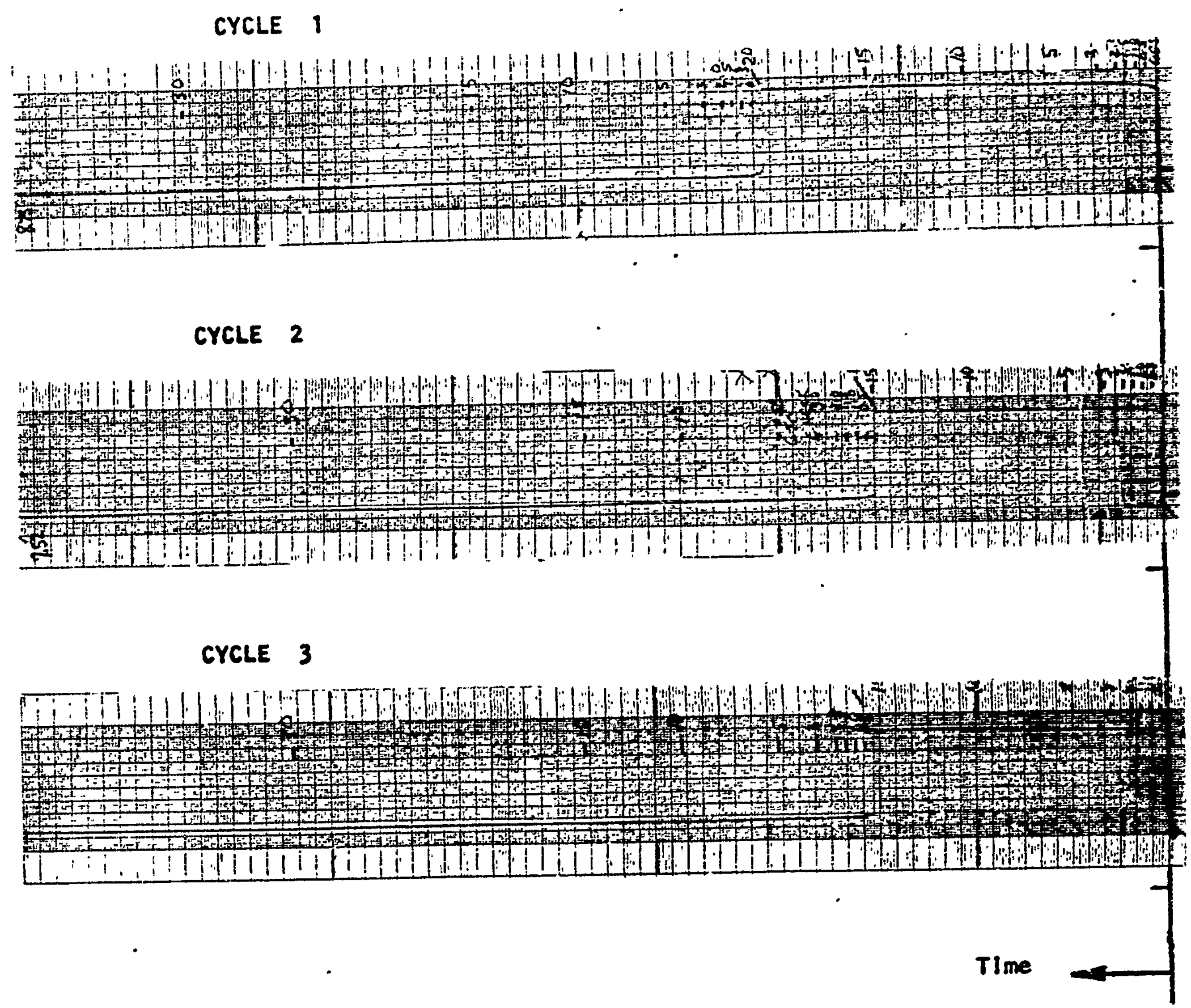


FIGURE 11-66 CREEP-RECOVERY CURVES FOR 90° SPECIMENS AT 170°F/dry% RH ENVIRONMENT AND 50% ULTIMATE LOAD LEVEL

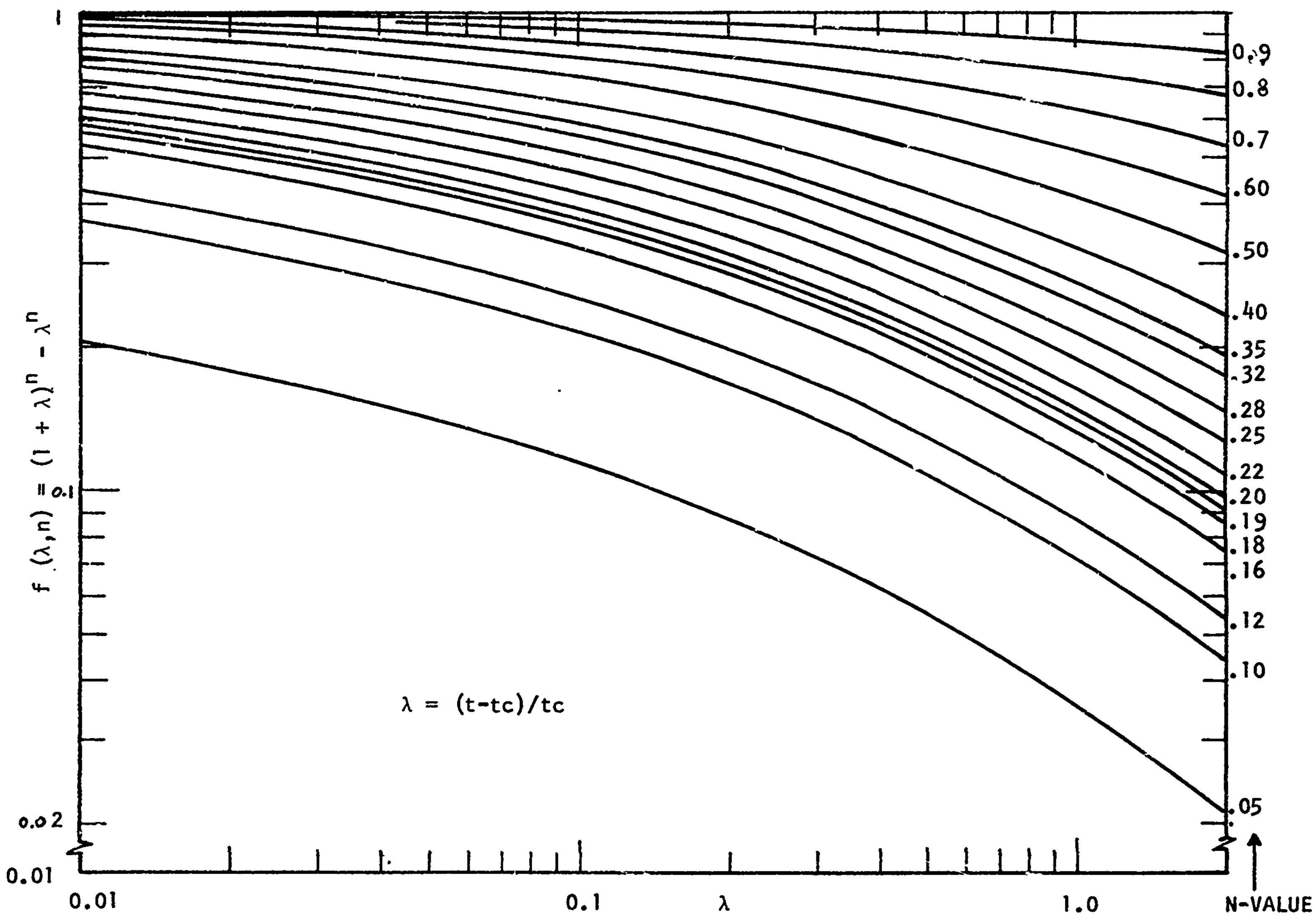


FIGURE 12 THE LOG $[(1+\lambda)^n - \lambda^n]$ VERSUS λ CURVE

5.0 REFERENCES

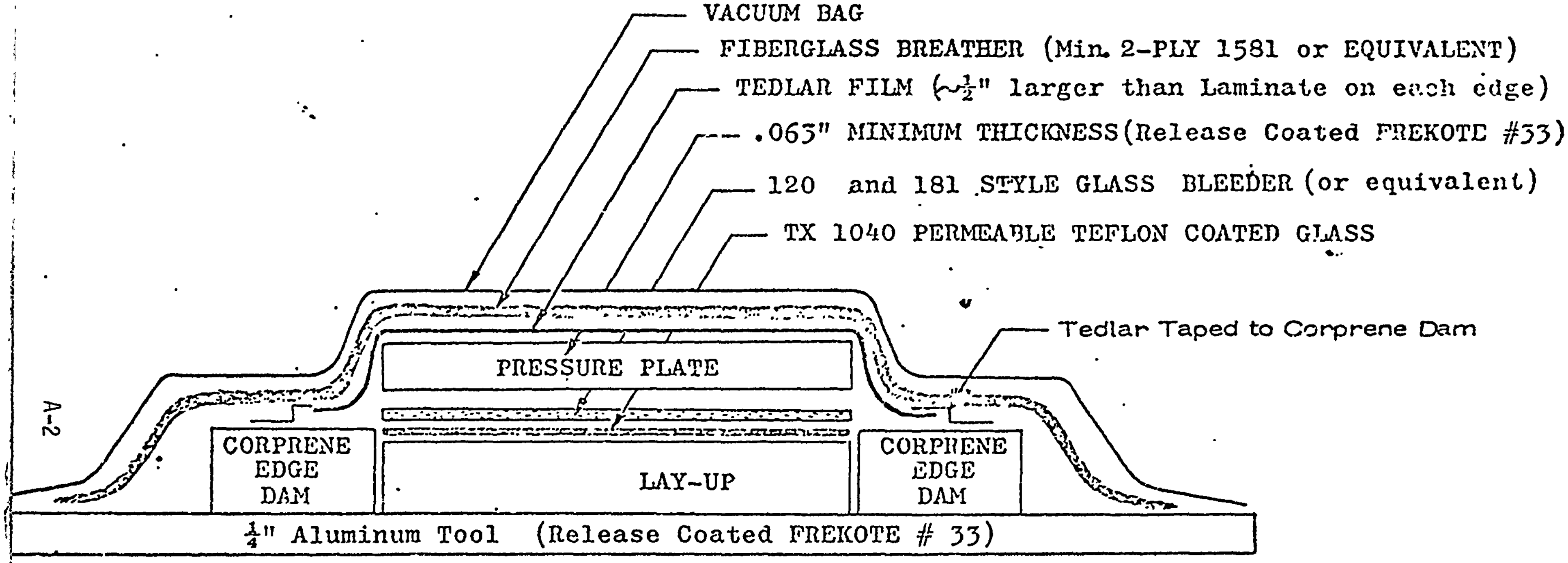
1. Ho, T and Schapery, R. A., "The Effect of Environment on the Mechanical Behavior of AS/3501-6 Graphite/Epoxy Material, Phase III," NASC Contract No. N00019-79-C-0581, ATC Report No. R-92100/1CR-5, January 1981.
2. Ericksen, R. H. and Guess, T. R., "Room Temperature Transverse Compressive Creep of Thick Kevlar Fabric/Epoxy Laminates," 12th National SAMPE Technical Conference October 7-9, 1980.
3. Allred, Ronald E., "The Effect of Temperature and Moisture Content on the Flexural Response of Kevlar/Epoxy Laminates: Part I (0/90) Filament Orientation," Journal of Composite Materials, Vol. 15, 1981.
4. Smith, W. S., "Environmental Effects on Aramid Composites," Conference on Advanced Composite - Special Topics, El Segunda, CA., December 4-6, 1979.
5. Lou, R. C. and Schapery, R. A., "Viscoelastic Characterization of Nonlinear Fiber-Reinforced Plastic," Journal of Composite Materials, Vol. 5, 1971.
6. Ho, T. L. and Renton, W. J., "The Effect of Environment on the Mechanical Behavior of AS/3501-6 Graphite/Epoxy Material," Final Report on NASC Contract No. N00019-77-C-0369.
7. Schapery, R. A., "Deformation and Failure Analysis of Viscoelastic Composite Materials," ONR Contract No. N00014-75-C-0325, Proceedings ASME National Meeting, Special Session on Inelastic Behavior of Composite Materials, November 1975, p. 127.
8. Roylance, M. E., and Roylance, D. K., "The Effect of Moisture of the Fatigue Resistance of an Aramid-Epoxy Composite," Organic Coatings and Plastics Chemistry, Vol. 45, August 1981.
9. Roylance, M. E., "The Effect of Moisture on the Properties of an Aramid-Epoxy Composite," Ph.D. Thesis, Department of Material Science Engineering, MIT (1980).
10. Schapery, R. A., "On Viscoelastic Deformation and Failure Behavior of Composite Materials with Distributed Flaws," ONR Contract No. N00014-75-C-0325, Texas A&M Report MM 3168-81-10, August 1981.
11. Tsai, S. W. and Hahn, H. T., "Introduction to Composite Materials," Technomic Publishing, 1980.

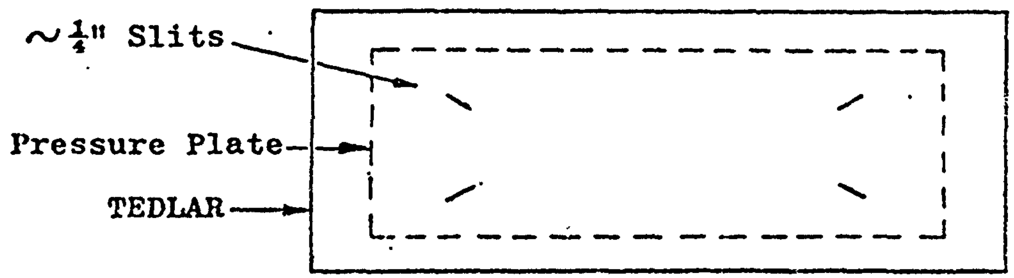
APPENDIX A

NARMCO KEVLAR 49/5208 SYSTEM LAYUP AND CURE PROCEDURE

LAY-UP SYSTEM

(Not to Scale)





Top View showing

TEDLAR Slits, away from the corners

SOURCES

1. TX 1040
   Pallflex Corporation
   Kennedy Drive
   PUTNAM, Conn.
2. CORPRENE DK-153
   Western Gasket
   3007 Fruitland
   LOS ANGELES, Calif.
3. FREKOTE # 33
   Frekote, Inc.
   112 W. Bennett
   GLENDORA, Calif.

Rev. 10/77

NARMCO KEVLAR 49 WOVEN
PREPREG SYSTEMS

The 5208 resin based prepregs are intended for use at elevated temperatures up to 400°F (205°C) whereas the 3203 resin is suitable for use at temperatures up to 200°F (93°C).

Lay-up procedures and autoclave cure cycles for the two types of prepregs are different.

The 5208 resin based prepreg systems shall be prepared for curing per the illustrated procedure.

AUTOCLAVE CURE CYCLE (NARMCO STANDARD PROCEDURES)

Step	5208
1) Initial pressure	22" Hg vacuum min. (0.95 kgf/cm^2)
2) Initial heat rise	RT-275 $^{+5}_{-10}$°F (135 $^{+3}_{-6}$°C) @ 4-6°F/min. (2-3°C/min.)
3) Dwell	60 min. beginning @ 265°F (129°C) part temp.
4) Pressurize	Apply 85-100 psig (6-7 kgf/cm^2) vent at 20 psig (1.4 kgf/cm^2)
5) Final heat rise	275 $^{+5}_{-10}$°F (135 $^{+3}_{-6}$°C) to 355 $^{+10}_{-5}$°F (179 $^{+6}_{-3}$°C) @ 4-6°F/min. (2-3°C/min.)
6) Cure	120 ± 5 min. @ 355 ± 10°F (179 $^{+6}_{-3}$°C)
7) Cool down	Cool to 140°F (60°C) or below under pressure
8) Post Cure (optional) (not normally required)	Place unrestrained part on honeycomb core in air circulating oven. Raise temperature from RT to 400 ± 5°F (204 ± 3°C) @ 4-5°F/min. (2-3°C/min.). Post cure 4 hours @ 400 ± 5°F (204 ± 3°C).

NOTE:

Lower heat rise rates will require shorter dwell times. Example: For 2-3°F/min. (1.0-1.7°C/min.), reduce dwell to 45 min.; for 1-2°F/min. (0.5-1.0°C/min.), reduce dwell to 30 min.

APPENDIX B

VOUGHT KEVLAR 49/5208 SYSTEM
LAYUP AND CURE PROCEDURE

PREPARED BY: G. Bourland 2-53450 W.G. Petty 2-50360 DISTRIBUTION ____	VOUGHT SYSTEMS DIVISION LTV AEROSPACE CORPORATION P O BOX 5907 · DALLAS TEXAS 75222 ENGINEERING DEPARTMENT SPECIFICATION	NO. 207-8-410/1A-1 PAGE 1 OF 2 DATE 28 August 1975
CODE IDENT NO. 80378	CONTR NO. F33615-73-C-5066	

OFFICIAL ENGINEERING RELEASE

AMENDMENT NO. 1

MATERIAL SPECIFICATION

GRAPHITE FIBER TAPE AND SHEET,

EPOXY RESIN IMPREGNATED,

FOR 260°F (127°C) CURE AND 180°F (82°C) SERVICE

APPLICABILITY:	This amendment forms a part of 207-8-410/1 and is applicable wherever 207-8-410/1 is called out.
CHANGE SUMMARY:	1. Revised fiber volume. 2. Revised Figure 1.
INCORPORATION DATE:	On or before 26 September 1975

Page 5, Paragraph 3.5.4, Change to read as follows:

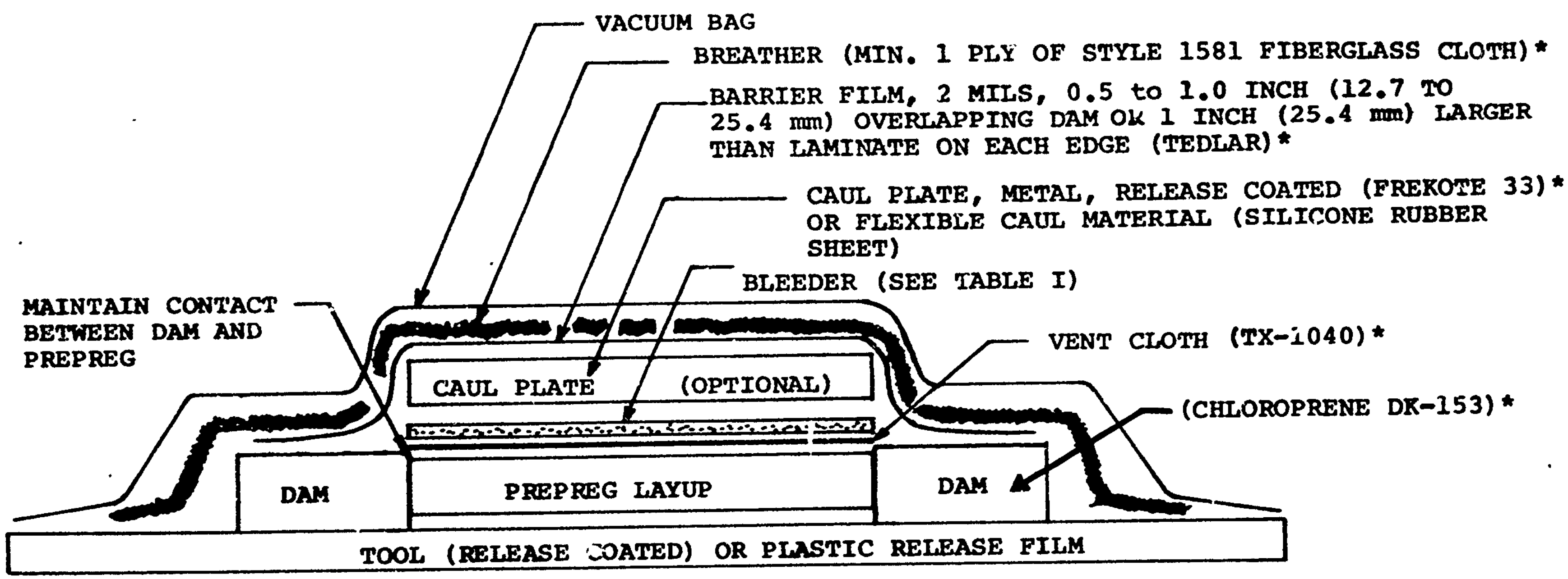
3.5.4. FIBER VOLUME - Shall be 64 ±2%. Acid shall be reagent grade concentrated nitric acid and temperature shall be 200°F (93°C). A fiber density of 1.74 shall be used to calculate fiber volume.

Page 7, Figure 1, Replace with page 2 of this amendment.

APPROVALS

PREPARING ACTIVITY	PROJ. ENGR.	TECH DATA SERVICES	COGNIZANT ACTIVITIES		
AB 8-12 [signature]	C.R. Foreman	AR McCoy			
DATE 8-12-75	DATE 8-21-75	DATE 8-12-75	DATE	DATE	DATE

2-56100 R7



* OR EQUIVALENT

NOTES

1. Slits approximately 0.125 inch (3.17 mm) long shall be placed in barrier film periphery at each corner.

2. This panel shall be a 16 ply thickness (0.080 ±0.006 inch) (2.03 ±0.152 mm) for all specimens except 0° tensile and compression which are 6 ply thickness (0.030 ±0.003 inch) (0.762 ±0.076 mm).

Layup System for Prepreg Parts
(Not To Scale)

4.8.1.2.4 Prior to any tooling being accepted for cure cycle control by temperature sensors, that tooling must first be qualified by correlating the permanent sensors with thermocouples embedded strategically in the laminate.

4.8.1.2.4.1 This correlation must be demonstrated on a minimum of 3 production runs. The tooling shall be placed randomly when an oven or autoclave is used.

4.8.1.2.4.2 The correlation must show that all laminates, as indicated by thermocouples, can be controlled for rate-of-rise and cure temperature by the thermal sensors, and are within specification requirements.

4.8.1.2.4.3 Any major tool rework or redesign requires a new thermal sensor profile be established prior to eliminating thermocouples for production.

4.8.1.2.4.4 Any replacement or relocation of thermal sensors shall require re-correlation of the new thermal device with the original device or with other calibration devices.

4.8.1.2.4.5 The recording chart printout points must be traceable as being from thermocouples or thermal sensing devices on all production runs whenever the two are mixed in the same autoclave or oven load.

4.8.1.2.4.6 When a correlation is established, Quality Assurance shall require permanent identification of the tool as being acceptable for bonding without thermocouples in the bondline. Whenever a correlation cannot be established, Quality Assurance shall reject the option and require thermocouples in the laminate. All tools not requiring part thermocouples must be identified. A permanent record of the correlation data shall be kept on file for MRB reference or other purposes. Quality Assurance may require a periodic requalification in accordance with 4.8.1.2.4 of the thermal sensor profile to ensure that the thermal sensors agree with part temperature.

4.8.2 PRESSURE SENSING REQUIREMENTS - To determine whether a pressure differential, between the areas above and below the pressure diaphragm, is being maintained requires the use of pressure sensing devices.

(a) Install pressure sensing devices adjacent to the assemblies and so distributed as to provide the best possible representation of the pressure under the diaphragm.

(b) Automatic recording instrumentation is recommended for continuous monitor recording of the pressure under the diaphragm. The recorder shall be capable of recording over a range from a maximum vacuum equal to 30 inches of mercury to a maximum gage

4.8.3 AUTOCLAVE CURE CYCLE

(a) Place bagged layup or assembly under 22 inches Hg vacuum minimum. Check for bag leaks. Leaks greater than 0.5 inch Hg per minute shall be repaired.

(b) Insert part in autoclave at room temperature to 130°F. Apply autoclave pressure of 85 ± 5 psig and vent bag to atmosphere at 20 psig minimum. Check for back pressure. Repair leaks which cause back pressure greater than 5 psig. Repaired bag assemblies shall be replaced in autoclave and pressurized to 85 ± 5 psig and proceed with step (c).

(c) Heat to 165°F ± 10°F and hold for 120 ± 10 minutes. Check for back pressure at start and end of hold period. Repair leaks which cause back pressure greater than 5 psig. Repaired bag assemblies shall be replaced in autoclave, and pressurized to 85 ± 5 psig and held at 165°F ± 15°F to accumulate a total time of 120 ± 10 minutes.

(d) Heat from 165°F ± 10°F to 350° ± 10°F at a rate of 2°F to 6°F per minute.

(e) Hold at 350°F ± 10°F for 120 ± 10 minutes. The lagging thermocouple shall be the controlling thermocouple for time at temperature. Check for back pressure at the beginning and end of cure period. Bagged assemblies may not be removed for repair.

(f) Cool under autoclave pressure until lagging thermocouple reaches 180°F or below, then release pressure and remove from autoclave.

DISTRIBUTION LIST

No. of Copies	To
1	Office of the Under Secretary of Defense for Research and Engineering, The Pentagon, Washington, D.C. 20301
12	Commander, Defense Documentation Center, Cameron Station, Building 5, 5010 Duke Street, Alexandria, Virginia 22314
1	Metals and Ceramics Information Center, Battelle Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201
	Office of the Deputy Chief of Staff for Research, Development, and Acquisition, Washington, D.C. 20310
2	ATTN: DAMA-ARZ
	Commander, Army Research Office, P.O. Box 12211, Research Triangle Park, North Carolina 27709
1	ATTN: Information Processing Office
	Commander, U.S. Army Materiel Development and Readiness Command, 5001 Eisenhower Avenue, Alexandria, Virginia 22333
1	ATTN: DRCLDC
	Commander, U.S. Army Electronics Research and Development Command, Fort Monmouth, New Jersey 07703
1	ATTN: DRDCO-GG-DD
1	DRDCO-GG-DM
	Commander, U.S. Army Armament Research and Development Command, Dover, New Jersey 07801
2	ATTN: Technical Library
1	DRDAR-SCM, Mr. J. D. Corrie
	Commander, U.S. Army Natick Research and Development Command, Natick, Massachusetts 01760
1	ATTN: Technical Library
	Director, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland 21005
1	ATTN: DRDAR-TSB-S (STINFO)
	Commander, Picatinny Arsenal, Dover, New Jersey 07801
1	ATTN: SARPA-RT-S
1	SARPA-FR-M-D, PLASTEC, A. M. Anzalone

DISTRIBUTION LIST

No. of Copies	To
	Commander, Redstone Scientific Information Center, U.S. Army Missile Research and Development Command, Redstone Arsenal, Alabama 35809
4	ATTN: DRDMI-TB
1	DRDMI-RLD, Mr. D. Loveless
1	DRDMI-EAM, Mr. H. Dedman
	Commander, U.S. Army Foreign Science and Technology Center, 220 7th Street, N. E., Charlottesville, Virginia 22901
1	ATTN: Mr. Marley, Military Tech
	Director, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604
1	ATTN: Mr. J. Robinson, DAVDL-E-MOS (AVRADCOM)
1	Mr. H. Reddick, DAVDL
	Naval Research Laboratory, Washington, D.C. 20375
1	ATTN: Dr. J. M. Krafft - Code 8430
1	Mr. I. Wollock
	Chief of Naval Research, Arlington, Virginia 22217
1	ATTN: Code 471
	Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433
2	ATTN: AFML/MXE, E. Morrissey
1	AFML/LC
1	AFML/LLP, D. M. Forney, Jr.
1	AFML/MBC, Stanley Schulman
	National Aeronautics and Space Administration, Washington, D.C. 20546
1	ATTN: Mr. B. G. Achhammer
1	Mr. G. C. Deutsch - Code RW
	National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama 35812
1	ATTN: R. J. Schwinghamer, EH01, Director, M&P Laboratory
1	Mr. W. A. Wilson, EH41, Building 4612
1	Ship Research Committee, Maritime Transportation Research Board, National Research Council, 2101 Constitution Ave., N. W., Washington, D.C. 20418
1	Materials Sciences Corporation, Blue Bell Office Campus, Merion Towle House, Blue Bell, Pennsylvania 19422

DISTRIBUTION LIST

No. of Copies	To
1	Dr. Clayton May, Lockheed Missile and Space Company, Incorporated, Department 47-01, Building 150, P.O. Box 504, Sunnyvale, California 94088
1	R. E. Hoffman, Hercules, Incorporated, P.O. Box 98, Magna, Utah 84044
1	Judy S. Chen, M.S. 73-43, Boeing Commercial Airplane Company, Seattle, Washington 98008
1	Robert Holden, Grumman Aerospace Corporation, Bethpage, New York 11714
1	Dr. David Kaelbe, Rockwell Science Center, 1049 Camino Dos Rios, P.O. Box 1085, Thousand Oaks, California 91360
1	Dr. Carl Zweben, General Electric Company, Space Systems Division, Valley Forge Space Center, P.O. Box 8555, Philadelphia, PA 19101
1	Dr. Donald Huang, E. I. Dupont de Nemours and Company, Incorporated, Polymer Products Department, Experimental Station Laboratory, Wilmington, Delaware 19898
1	John Schibler, Non-Metallics, Hughes Helicopter, Culver City, California 90230
1	Dr. Jeanne Courter, Room 319, American Cyanamid Compoany, 1937 West Main Street, Stamford, Connecticut 06904
	Naval Air Development Center, Warminster, Pennsylvania
1	ATTN: R. Trabocco
1	L. Buckley
1	Dr. R. Wilkins, General Dynamics Corporation, P.O. Box 748, Fort Worth, Texas 76101
1	Mr. Maxwell Stander, Naval Air Systems Command, Washington, D.C. 20361
	E. I. Dupont de Nemours and Company, Incorporated, Special Products Division, Wilmington, Delaware 19898
1	ATTN: Paul Langston
1	Paul Riewald
1	David Crabtree, Northrop Corporation, Hawthorne, California 90250
1	Don Crozier, Lockheed California Company, B/229, PH2 (Dept. No. 74-71), P.O. Box 551, Burbank, California 91520

DISTRIBUTION LIST

No. of Copies	To
1	J. F. Carpenter, McDonnell Douglas Corporation, McDonnell Aircraft Company, P.O. Box 516, St. Louis, Missouri 63166
1	Dr. T. Helminiak, AFML/MBC, Wright-Patterson Air Force Base, Ohio 45433
1	Dr. R. Van Deusen, AFML/MBP, Wright-Patterson Air Force Base, Ohio 45433
1	Dr. Chet Poranski, Naval Research Laboratory, Code 6110, Washington, D.C. 20375
1	Dr. Anthony Davis, Procurement Executive, Ministry of Defense, Non-Metallic Materials Branch, Waltham Abbey, Essex, England
1	Dr. Roger Morgan, Lawrence Livermore Laboratory, University of California, Livermore, California 94550
1	Paul Scherer, McDonnell Douglas Corporation, Huntington Beach, California 92646
1	Dr. J. Cernosek, Bell Helicopter Textron, Department 80, P.O. Box 482, Fort Worth, Texas 76101
	Director, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172
2	ATTN: DRXMR-PL
1	DRXMR-AT
1	DRXMR-FD
1	DRXMR-K
6	DRXMR-OC, M. Roylance

AD ________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
THE EFFECT OF ENVIRONMENT ON THE MECHANICAL BEHAVIOR OF KEVLAR/EPOXY MATERIAL
T. Ho
Vought Corp. Advanced Technology Center
P. O. Box 226144
Dallas, Texas 75266
Technical Report AMMRC TR82-11, March 1982, 120 pp.
Illus.-tables, Contract DAAG46-80-C-0037
D/A Project 2102040 06A 7001,
AMCMS Code 612105.H840011
Final Report, May 1980 to September 1981

Key Words

Deterioration
Viscoelasticity
Mechanical Properties
Kevlar Epoxy

Applicability of a viscoelastic characterization to Kevlar 49/5208 material under severe environment was investigated. Specific studies include development of properties reflecting material dependence on time, temperature and humidity and resolution of the question as to whether a specific thermal conditioning environment can be directly substituted for a specific moisture conditioning environment over a prescribed temperature vs. humidity range. Specimens with 0°, 90° and ±45° layup were used for creep-recovery tests in various environments. Test data were analyzed by using a viscoelasticity theory and power law representation of the creep compliance. Stress dependence of the material is emphasized to account for non-linearity.

AD ________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
THE EFFECT OF ENVIRONMENT ON THE MECHANICAL BEHAVIOR OF KEVLAR/EPOXY MATERIAL
T. Ho
Vought Corp. Advanced Technology Center
P. O. Box 226144
Dallas, Texas 75266
Technical Report AMMRC TR82-11, March 1982, 120 pp.
Illus.-tables, Contract DAAG46-80-C-0037
D/A Project 2102040 06A 7001,
AMCMS Code 612105.H840011
Final Report, May 1980 to September 1981

Key Words

Deterioration
Viscoelasticity
Mechanical Properties
Kevlar Epoxy

Applicability of a viscoelastic characterization to Kevlar 49/5208 material under severe environment was investigated. Specific studies include development of properties reflecting material dependence on time, temperature and humidity and resolution of the question as to whether a specific thermal conditioning environment can be directly substituted for a specific moisture conditioning environment over a prescribed temperature vs. humidity range. Specimens with 0°, 90° and ±45° layup were used for creep-recovery tests in various environments. Test data were analyzed by using a viscoelasticity theory and power law representation of the creep compliance. Stress dependence of the material is emphasized to account for non-linearity.

AD ________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
THE EFFECT OF ENVIRONMENT ON THE MECHANICAL BEHAVIOR OF KEVLAR/EPOXY MATERIAL
T. Ho
Vought Corp. Advanced Technology Center
P. O. Box 226144
Dallas, Texas 75266
Technical Report AMMRC TR82-11, March 1982, 120 pp.
Illus.-tables, Contract DAAG46-80-C-0037
D/A Project 2102040 06A 7001,
AMCMS Code 612105.H840011
Final Report, May 1980 to September 1981

Key Words

Deterioration
Viscoelasticity
Mechanical Properties
Kevlar Epoxy

Applicability of a viscoelastic characterization to Kevlar 49/5208 material under severe environment was investigated. Specific studies include development of properties reflecting material dependence on time, temperature and humidity and resolution of the question as to whether a specific thermal conditioning environment can be directly substituted for a specific moisture conditioning environment over a prescribed temperature vs. humidity range. Specimens with 0°, 90° and ±45° layup were used for creep-recovery tests in various environments. Test data were analyzed by using a viscoelasticity theory and power law representation of the creep compliance. Stress dependence of the material is emphasized to account for non-linearity.

AD ________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172
THE EFFECT OF ENVIRONMENT ON THE MECHANICAL BEHAVIOR OF KEVLAR/EPOXY MATERIAL
T. Ho
Vought Corp. Advanced Technology Center
P. O. Box 226144
Dallas, Texas 75266
Technical Report AMMRC TR82-11, March 1982, 120 pp.
Illus.-tables, Contract DAAG46-80-C-0037
D/A Project 2102040 06A 7001,
AMCMS Code 612105.H840011
Final Report, May 1980 to September 1981

Key Words

Deterioration
Viscoelasticity
Mechanical Properties
Kevlar Epoxy

Applicability of a viscoelastic characterization to Kevlar 49/5208 material under severe environment was investigated. Specific studies include development of properties reflecting material dependence on time, temperature and humidity and resolution of the question as to whether a specific thermal conditioning environment can be directly substituted for a specific moisture conditioning environment over a prescribed temperature vs. humidity range. Specimens with 0°, 90° and ±45° layup were used for creep-recovery tests in various environments. Test data were analyzed by using a viscoelasticity theory and power law representation of the creep compliance. Stress dependence of the material is emphasized to account for non-linearity.